NASA SP-211

FUTURE FIELDS OF CONTROL APPLICATION

A symposium held at
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS
February 10-11, 1969

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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A symposium sponsored by
NASA Electronics Research Center, and held at
Massachusetts Institute of Technology,
Cambridge Massachusetts, February 10-11, 1969

Scientific and Technical Information Division
OFFICE OF TECHNOLOGY UTILIZATION 1969
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

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FOREWORD

The Symposium on "Future Fields of Control Application" took place on February 10 and 11, 1969, as planned, despite one of the worst blizzards to hit the Northeast in years. Several speakers and many participants could not reach Boston at all; others were delayed many hours because of the storm. Nevertheless, I feel that the papers that were presented and the discussions that followed were stimulating and fulfilled the objectives of the Symposium.

In my letter of invitation (dated January 27, 1969), I stated the rationale for the Symposium in the following way:

> *"It is the mission of the Office of Control Theory and Application (OCTA) to improve the nation's control abilities in the aeronautical and space areas. However, recognizing the value of applications in other areas — in terms of insights and reduced risks — this office encourages their consideration as well. It is, accordingly, the purpose of our Symposium in February to give the participants an opportunity to discuss the nature of the problems existing and anticipated in the transportation, bio-medical, economic, social, production, and communication areas. These were the areas identified in a recently completed national survey of control specialists as those in which control concepts and technology would, in the future, have their greatest impact on the nation's progress."*

If you were not able to attend the Symposium, I hope that the record of the proceedings that follows will help convey the excitement that is always generated when people with widely varying backgrounds get together to discuss some of the crucial topics of our time.

Originally we intended to have a complete transcript of each talk, but the storm precluded that, too. Instead, we have compiled these proceedings from several ingredients: the transcript of the Tuesday sessions, written papers prepared by some of the speakers, and, in a few cases, notes, taken during the Symposium, which were expanded into papers with the help of the original speakers.

We did not plan to do things this way; but one of the criteria of a good control system is flexibility--the ability to make the best of the unexpected. I hope that we at OCTA have been able to provide a useful document.

O Hugo Schuck

O. Hugo Schuck, Chief
Office of Control Theory
and Application

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WELCOMING ADDRESS*

JAMES C. ELMS
Director, NASA Electronics Research Center
Cambridge, Mass.

* * * * *

Good morning! It is my pleasure to welcome you to NASA's Electronics Research Center. I would have liked to bid you this welcome in our own permanent buildings, which will include an auditorium a little larger than this room. As some of you may have noticed as you came through Kendall Square, the low brick building--our new auditorium--is the furthest along of the buildings now under construction. However, it isn't finished, and we're very glad that MIT can accommodate us here today.

Many of you have come a long way to attend this Symposium, and some of you may have wondered why NASA should want this kind of contact with the technical community. Why not just go ahead with direct contact with contractors, send NASA employees to technical society meetings, and let it go at that? I think the answer is simple and straightforward--we can't learn enough if we

**Presented by O. Hugo Schuck, Chief, Office of Control Theory and Application, NASA Electronics Research Center* limit our contacts that way. Nor, we fear, can the technical community learn enough about us and our thinking in the constricted contractual relationship. In that relationship, with its concern for legal and financial considerations, the actual technical subject tends to come off second best. We need a mode of contact that allows us to put primary emphasis on the subject matter. It is to provide such subject matter-oriented contact that we set up meetings such as this.

One may well ask why this meeting is being sponsored by the Electronics Research Center. To answer requires an explanation of the Center's role in NASA. Briefly, our role is to assure that NASA's future activities, both in space and aeronautics, are supported by the best electronics possible. That means identifying what is going to be needed and then making sure that all the necessary research and development are being done--somewhere or, if necessary, right here at our Center.

When you look at NASA's activities to date, you see that they all have involved automatic control concepts and techniques. Accordingly, all of the various NASA organizations have developed some interest in control and, in most cases, have some organizational group working on control. However, it is control with respect to their particular line of interest--propulsion, aerodynamics, spacecraft, or whatever--and, for that reason, their approach unavoidably tends to be parochial. But NASA needs the broadest and most advanced approaches for its future controls, and to provide a central reference for all NASA's control work is the function of our Office of Control Theory and Application (OCTA). That's why it exists. Not only must that Office know what's going on control-wise and what's needed throughout NASA, but it must also know what's going on everywhere else. As you well know, there's a universality about control theory in its various application areas. So, a successful application of a new control theory in, say, chemical fields, may greatly reduce the risk in using it on a VTOL or a launch booster.

This means, of course, looking at the future: both NASA's activities and control activities in all other fields. To get a reasonably probable estimate of the future, one is well advised to supplement his own thinking by asking for the opinions of his knowledgeable friends. That was the point of the survey the Office of Control Theory and Application conducted last summer--to obtain the benefit of the insights and perception of the most knowledgeable control people in the country.

Many of you who are here responded to that survey, and I want to thank you for your cooperation. Some of your replies were almost essays; all were thoughtful and conscientious. The surprising thing, as the replies came in, was their consistency. People from industry, from academia, and from government agreed very well about the future of control, surmising that it would find its most important future applications in dealing with large-scale, multi-variable systems involving human beings.

In the normal course of events, the control fraternity would gradually get acquainted with those new application fields; and any cross-fertilization and risk reduction that might accrue to the aerospace field would come gradually. But we in NASA would like to accelerate the process. It's for this reason--admittedly a selfish reason--that we have sponsored this Symposium. You are all here with a similar motivation--to accelerate your acquisition of knowledge about these coming control fields. I speak for NASA in saying that I hope your motivations and hopes, and those of NASA, will all be satisfied in some degree.

POSSIBLE AREAS OF CONTROL THEORY IN PRINT COMMUNICATION

JOHN L. HALLENBECK
Vice President—TIME Incorporated
New York, N. Y.

* * * * *

I am very happy to appear today as kickoff speaker at this session of NASA's Symposium on "Future Fields of Control Application"--particularly because I expect to learn far more at these sessions than you could ever gain from what I'm about to tell you. I'm sure you know that we at *TIME*, Inc., are long-time enthusiasts of NASA. You may recall that, from the time the first seven astronauts were designated, LIFE contracted for the first-hand account of their exploits--from John Glenn and his original cohorts right down to the Apollo 8 team.

A FEW DEFINITIONS

Now, I'm not sure I know what "control theory" is, what it does, and what it is all about. But we at *TIME*, Inc., are very much in the business of communications, and I can describe for you what *TIME*, Inc., does in the conduct of its affairs in its particular segment of the communications industry. I hope what I have to tell you will provide you with the guidelines from which you can determine whether, or how, well control theory can be applied. So I think of my role here today as that of suggesting the problems, rather than stating them or giving answers. I'm sure most of this audience is better at stating problems and finding answers than I am.

Communications is a word that has been running into some semantic trouble of late. A great many of the large-sized "Help Wanted" ads in the Sunday *New York Times* and the *Wall Street Journal* have been pleading for a variety of communications experts and specialists. But, looking at the smaller print, I note that they are looking for systems analysts and computer experts--and not the kind of communications specialists that we in publishing always thought we were. So I had better begin by defining some terms and, that done, we may find that indeed there is a good deal of common ground to share.

An act of communication, in our terms, is the movement of a fact, thought, or idea from one mind to another mind. Now that is not some fancy rationalization arrived at neatly and long after the fact. Well before our company had ever published a magazine, 47 years ago, Henry Luce and Briton Hadden, the two young founders of *TIME*, Inc., issued a prospectus for their new venture. On page 1 of the 18-page document they wrote: "*TIME* is interested--not in how much it includes between its covers--but *in how much it gets off its pages into the minds of its readers."*

To accomplish such an act of communication requires at least three steps: the creation of the message, the transmission of the message, and the receipt of the message. And, as you might like to put it, the loop is closed for us when some indignant reader writes in and threatens to knock the editor's head off. Some feedback!

Up to this point, the two notions of communication may not be too far apart. Both involve the organization and manipulation of information. But they begin to diverge when one considers the character of the information involved, as well as the manner of its manipulation. Mass media, such as ours, necessarily deal with the *selection* of information--selection from a mass of facts and associations that is probably too large for any data bank and too cumbersome to gather into any reasonable form for input to a data bank. This information undergoes multiple filtering and reinforcing as it works its way through the minds of highly trained correspondents, writers, and editors, any one of whom may use his own considerable background to add to or subtract from the information to be conveyed.

What perplexes me, then--and this may be the first problem whose nature I am suggesting--is what appears to be a philosophical contradiction between the very concept of control and our own notion of communication. Control suggests a kind of ultimate in pure objectivity and impersonality, while our notion of communication, in its most advanced and professional form, has an extraordinarily high content of subjectivity and personality. In creating messages that are to move from mind to mind, we need the wisdom and judgment of our most capable individuals. If anything, we treasure their *un*-controlled imagination and creative insights.

I have already stated that we are in the mass media segment of the information business. Now I would like to narrow that down somewhat and point out that we are primarily in the magazine business. This is not to suggest that we think magazines will continue to play their present major role forever. We are very much aware of other media, both those that are in being and those that are in contemplation, and we realize that other media may one day replace magazines as we know them. We do not, however, think of their demise as imminent. Our own plans and forecasts for a variety of purposes extend to 1980 and 1985; and we don't think of these as especially long-range. When I speak of magazines as we know them, I refer to magazines as *printed* media. There may well be, way out there, some far better means of distributing this kind of information than by turning trees into white paper with marks on it; but, for a considerable period to come, we foresee that this method will show the best cost-benefit ratio. Printed magazines, I feel certain, will still be a major form of communication in the year 2000. Indeed, the symbolism of print has such broad and basic appeal that I somehow doubt that it will ever go out of style.

THE BUSINESS OF *TIME*, INC.

Well, what is this business that *TIME*, Inc., is in, and just what part does it play in the communications industry? Functionally, our activities might be divided into five segments described as journalism, manufacture of product, sale and delivery of the product, sale of advertising space, and collateral activities.

The first of these, journalism, might be said to be the reason for our existence. The basic function we perform for society is a journalistic one--the collection, organization, and expression of facts relating to events throughout the world, presented in a manner that can provide a desired service for a large number of individuals. Facts, of course, can take the form of either words or pictures, and be displayed in color or in black and white. As already noted, gathering and conveying information of this kind with taste and intelligence is an extremely complex procedure that requires very high levels of ability, skill, and talent. This function is the same as that described earlier as "the creation of the message," and it would still be needed even if the printed page were to be superseded eventually by some other medium of communication.

Our second major function is the manufacture of the product, and, in our case, it consists to a large degree in the printing and production of magazines. This has sometimes been called the "packaging" of our product, but it is really more than that. Print is actually a representation of facts and ideas, and the processes it entails are much more demanding than that of merely producing a wrapping or a box. It entails all the steps usually associated with manufacture--providing and procuring raw materials, bringing those raw materials to a central point of assembly, and then processing them into the product that is designed for the consumer. As I will describe in some detail later, this is the area in which we have already sought to institute control procedures in the interest of greater speed and efficiency.

The third function -- sale and delivery of the product--gets us into some very interesting aspects of our kind of business. The traditional way to rationalize the economics of a manufactured product is to sell it at some price exceeding the cost of manufacture, distribution, and sale. In the case of most printed media in this country, however, the selling price often barely covers the cost of distribution and sale alone. The recognition of this fact, coupled with the government-accepted concept of the widest possible dissemination of information (akin to the freedom of press principle), has led to special postal rates for various classes of printed materials. But there are problems other than rates--the distribution of national magazines is the kind of traffic control program with which many of you are familiar, with the largest variable consisting of the services provided by the Post Office, and the second largest being the irregularity and inconsistency of the various means of transportation. Since our magazines are sold mainly by subscription, there is also the problem of establishing and maintaining a large volume of records. In this area--known in our business as "circulation fulfillment"--*TIME*, Inc., has long tried to be in the vanguard of those employing new technology, and we were one of the first, if not the first, to use electronic data processing for keeping files of this kind.

And now to the fourth function of our business - sale of advertising space. The deficits that are incurred in the creation of our products are, fortunately, more than made up in the sale of advertising space. In using our magazines the advertiser gets considerably more than the white space on the page on which his message is imprinted. To be sure, he is renting that space, and this means that his message has a good chance of reaching a certain number of millions of our readers. These are not just numbers, however, but readers of a certain kind and character, consonant with the quality and reputation of the magazines. But along with the message he delivers, the advertiser also gets to be a kind of hitch-hiker on the credibility of the magazine--or newspaper, or television program, or whatever medium he chooses. But because his message can also influence *our* credibility, we have a special department at *TIME*, Inc., that passes on the acceptability of advertising copy, guided by such standards as honesty, integrity, and good taste.

That leaves just the final function of collateral activities. Some of these are fascinating, but I will touch on a few of them, and only briefly, to suggest their relationship to our principal area of concentration.

Our international publishing is really an extension of our domestic publishing activities, since the magazines we print and distribute abroad are essentially the same as those we publish in this country, at least as far as editorial content is concerned. It is of some interest to note that we went into international publishing immediately after World War II, at a time when we expected those activities to result in a substantial loss, but with the basic purpose of providing "a projection of America" overseas. We did indeed operate at a loss for some years, but happily international business generally has become more profitable and we have been able to share in its benefits. In terms of the speed of distributing our products to all parts of the world, there are still some important logistical problems. We have alleviated them to some degree by establishing printing locations abroad, but have not really come close to solving the problems yet.

The next activity I would like to mention is book publishing and, although we have been in this business for less than a decade, its size and extent is such that I sometimes wonder just how collateral it really is. We first got into book publishing when we found we could not resist putting some major editorial features from our magazines into hard covers. The standards of typography, make-up, and print qualities we had long used were much closer to those normally associated with high-quality book publishing than to news reporting. At least we had come a long way from the period in the 1920's when Robert Benchley said that *TIME's* illustrations looked like 18th century prints engraved on French bread. Since establishing its own rather substantial book publishing operations, *TIME*, Inc., has purchased a textbook publishing company, a trade book publisher, and a publisher of fine art prints and reproductions.

The third collateral area is that of radio and television broadcasting. While this would seem to betoken a kind of disloyalty to print media, I would like to remind you that *TIME*, Inc., regards itself as fundamentally in the business of communications and has long exhibited a lively interest in electronic communication. As far back as 1924, we created and produced a kind of news quiz show on radio; in the 1930's and 1940's we produced one of the most popular radio shows of that time - *The March of Time*. We once owned a substantial interest in one of the major radio networks; we have at various times produced television shows and documentary series, and our ownership of stations dates back to the early 1950's. More recently, we have acquired various broadcast interests overseas, most of these in the form of minority interests or joint ventures with partners in Europe, Asia, Latin America, and Australia.

We also have substantial interest in pulp and paper mills. We first acquired such interests as a direct consequence of wartime paper shortages, when our magazines were growing faster than most, but were allocated paper based on their much smaller pre-war consumption requirements. To guard against a recurrence of this situation, we bought interests in various paper mills, but over a period of time disposed of most of them. We were instrumental in creating a major new pulp and paper mill in southeast Texas, which, though it produces no magazine papers, enabled us to use and build on the paper-making know-how that we had acquired. Incidentally, it has turned out to be an extremely fine investment. Finally, we became a 50-50 partner in another large paper mill in St. Francisville, Louisiana, and this one *does* produce a substantial amount of the paper used in our magazines.

Finally, there are the research and development activities in all areas of the graphic arts, which are carried on at our laboratories in Springdale, Connecticut. One offshoot of this has been our wholly-owned subsidiary, Printing Developments, Inc. (PDI), formed originally to market an electronic scanner developed at Springdale for making color separations for printing plates. PDI has since taken on a broad line of new and promising products, developed at Springdale and elsewhere, in various areas of the graphic arts.

This, then, is the broad picture of *TIME*, Inc., and its activities. I would like, however, to narrow it down considerably for the purpose of giving you some detailed illustrations of our activities. And I have chosen for this purpose to concentrate on *TIME*, The Weekly Newsmagazine.

A CLOSER LOOK AT THE *TIME* MACHINE

First, *TIME* is nothing, if it is not a journalistic enterprise. Almost all its news is gathered by our own reporters in the field rather than taken from a wire service shared with other clients. Much of this activity is carried on by full-time correspondents stationed in news bureaus all over the world. In addition, we make use of part-time "stringer" correspondents in cities or areas where we do not have regular correspondents. Full-time reporters, headquartered in New York, concentrate on such special areas of news coverage as education or entertainment.

From this network comes a weekly flow of millions of words, by leased wire, Telex circuits, overhead wires and cables, telephone and, sometime, for longer-range news projects, by mail or by hand. A much smaller work total, but a similar number of messages goes out from the New York editors to these news-gatherers. Pictures come from correspondents; they are assigned to photographers, and they are gathered from standard sources by picture researchers. A New York staff of writers, editors, and researchers gathers additional information and reads, sorts, shifts, and winnows this mass of material, reducing it to an informative, sense-making, and usually handsome package for the reader to sift, sort, and digest in his turn.

But it does not get to the reader until it has first been manufactured and then delivered. For all of *TIME*, Inc.'s printed products, we use 10 paper mills, 14 printing plants, innumerable carriers involving all modes of transportation, and virtually every part of the United States Post Office, in order to print and distribute 750 million magazines and 18 million books a year. *TIME* itself is printed, bound, and shipped from six locations--Chicago, Los Angeles, Albany, Atlanta, Old Saybrook, Connecticut; and Washington, D.C. Overseas editions of *TIME* are manufactured in Paris, Panama, Tokyo, Melbourne, Australia, and New Zealand. Each week, some 4 million copies of *TIME* are printed by both offset and letterpress printing processes.

As I have said, *TIME* is edited--that is, the final form it will take is determined--in one place, but the product is actually manufactured in several locations. That means that something has to move several hundred or several thousand miles before production of the magazines can even start. That is not a particularly serious problem as far as words are concerned; they can be transmitted to the printing locations in a variety of ways, with high speed and all but absolute fidelity. But pictures and layouts are another matter. And while *TIME* is primarily a "word" magazine, doubtless you may have noticed the steadily increasing amounts of full-color illustrations that are used, not to mention the considerable quantity of advertising copy and illustration.

This poses a proposition that is probably a familiar one to all of you--that is, the consideration of transportation versus communication and all the various trade-offs that are possible among such factors as speed, reliability, flexibility, quality, and, of course, economics. I will mention some of the things we are doing and contemplating in this area a little later. But I cannot resist pointing out that one of the respondents to the recent NASA survey made a similar observation when he said, "The transportation problem can be sidestepped if the need to move people is reduced ... This should be possible by improving communication channels and remote control techniques." I would like to expand that observation by noting that there is a need to sidestep the transportation problems in moving certain kinds of *things*, as well as people.

Some of the other considerations related to manufacturing are those involving materials and methods. The assurance of paper supplies goes all the way back to such things as the planting of seedlings, forestry, and insect control. We engage in these activities at our East Texas plant, where we own woodlands that are about as extensive as the state of Rhode Island. (As I said, this plant does not make magazine papers.) Our task with regard to paper for printing *TIME* goes back no further than arranging for the purchase, shipment, and warehousing of appropriate quantities of paper to each of our printing locations. We are also concerned with paper grades and weights, and we are constantly researching ways and means to get cheaper yet better paper for our magazines.

One of the places where we come closest to being satisfied with the efficiency of our operations is in the area of product sales and fulfillment--or, at least, the area involved with the mechanics of these functions. Millions of letters are sent out each year to request subscribers to renew their subscriptions to *TIME*. Millions more are mailed in an effort to get new subscriptions, in order to continue the magazine's circulation growth and to replace the relatively small proportion of subscribers who fail to renew. I know you have received some of these letters yourselves. It is the function of the Subscription Service (or fulfillment) group to handle this massive flow of information and materials, and to maintain and update the subscription records which are affected by this communications flow.

For a great many years, our Subscription Service operations went through one crisis after another, as both the number of magazines we published and circulation of each kept expanding. This called for either a steady increase in the number of warm bodies employed to handle this function or finding some more efficient means of getting it done. We went through several systems employing mechanized equipment for maintaining records and printing address labels before we started using computers. Even so, we were among the first users of electronic data processing and we are now using third-generation computer systems along with sophisticated software.

TIME, which was once thought of as something of a specialized magazine--like *Yachting* or *Scientific American*--failed to live up to that billing. With a growing circulation, now passing 4,000,000, *TIME* must be regarded as a mass magazine.

TIME advertising salesmen who call on advertisers and advertising agencies must make known the advantages and benefits of reaching an audience of the nature and character of one that reads *TIME*. I almost included "size" as one of the characteristics of *TIME* audience, but most advertisers are more interested in costs per thousand readers than in the overall audience size--and *TIME's* cost per thousand, incidentally, is pretty high, as general magazines go. Thus, a good many advertisers are interested in reaching only a part of *TIME's* audience, and they have been afforded increasing flexibility in this respect over the past dozen years or so. Advertisers can choose to reach various regions in the U.S., or they can narrow down their audience on a demographic basis, aiming their messages only at doctors, educators, or students. You may be interested to know that our advertising salesmen now have available to them portable teletype consoles, which can be tied in through telephone lines to a computer system. The data bank of this system includes audience figures on all major national media of communications. There are programs that can quickly work out the total reach of these media or of combinations of media, the frequency with which they reach members of their audience, and the costs of the advertising schedules involved.

All of these functions that I have been describing for *TIME*--journalism, product manufacture, product sales and delivery, and advertising sales--add up to the business known as magazine publishing. You can see that the whole equation is complex and interactive--and I do not envy the publisher who has to work out the programs and partial differentials that would determine the costs and benefits of a major change in any part of the equation. Would it be worthwhile, for example, to add 100,000 subscribers with some college education and incomes between $10,000 and $12,500, if the cost were 10 percent lower than adding the same number of subscribers with college degrees and incomes between $12,500 and $15,000? In terms of appeal to advertisers, there would have to be psychological costs and benefits, as well as purely economic ones, and the psychology would then somehow have to be translated into dollars and cents, as well.

INTRODUCTION OF NEW TECHNOLOGY IN MASS MEDIA COMMUNICATION

Let's leave that little problem to someone else, and I'll tell you a few of the things that we have been doing in terms of introducing new technology into our operations, and suggest some projections of technological improvements that are on the way to help make better magazines.

Until recently, progress in the graphic arts could best be described by one word: *appalling*. For a century or two, the printing industry had taken what can only be described as "baby steps" beyond the giant steps already made by Gutenberg and Mergenthaler in the invention of the printing press, movable type, and the linotype machine. This is especially disconcerting when we consider that the printing press may well have been the greatest single invention of civilized man, and the major force in leading him out of the darkness toward knowledge and enlightenment.

I don't know whether or how this foot-dragging can be explained, unless it is by a kind of tortoise-and-hare analogy. When one area of technology makes major forward progress, perhaps it is then inclined to relax and let other areas catch up, and then it relaxes so well that it falls asleep while the others pass it by.

Be that as it may, there has recently been such a resurgence in communications technology, including the graphic arts, that the vanguard of the industry might almost be described as being in a state of turmoil--or at least of ferment. And it is from a veritable feast of new developments that those of us in the industry make our choices.

The area that we selected for concentration is the one that seemed most susceptible to the introduction of new technologies with economic justification; i.e., the handling of news and information prior to the time it reaches the printing press. We refer to this period, appropriately enough, as the *pre-press* period.

We used a systems approach to the problem--that is, before making a change in any of the steps involved in handling information, we considered the effect of that change on other parts of the system. First, we established the objectives of the system we hoped to institute. Speed, always a critical factor in handling something as perishable as the news, was our first consideration. Quality of graphics also got high priority, both for the creation of an artistically superior product and for its special appeal to advertisers. In color reproduction, in particular, good graphics has a nearly tactile effect in suggesting texture or "feel" of a work of art or a commercial product. A third objective was flexibility that would permit an editor to communicate by a variety of graphic means. Overall, we hoped to get a superior product without increasing the costs of getting it to the press.

Before describing the direction in which we are moving, I would like to provide some perspective by describing the old ways of doing things and some of our requirements. First, a story written for *TIME* usually went through anywhere from three or four to a dozen steps, each of them involving some changes. It was written by a writer, edited by a senior editor, then edited by an assistant managing editor or managing editor or both, and finally checked by a researcher. It might be returned to the writer for a second or third or even a fourth version, or to the senior editor for re-editing. It might be crowded out of one week's issue, but saved for the following week, when it would have to be rewritten for updating. For most or all of these handlings, the story was typed by members of a typing staff, known as the "copy" desk. And finally, when a story was ready for the magazine, it was printed on special teletypesetting machines that measured the length of each unit, according to linotype specifications. An editor would then have to fit the copy to the allotted space by adding to or deleting from the story, usually the latter. And since a *TIME* story often has material at the end that is just as important as that at the beginning, the old newspaper device of "taking it off the bottom" was not applicable.

For a variety of reasons, it made little sense for a writer or editor to wait hours for a story to be typed or to learn that his words did not fit, when it was becoming physically possible for him to wait only a few minutes. Similarly, an art director should not have to wait days to see a color proof or hours to see a layout, when he could have the proof in hours and the layout in minutes. The creative time and energy dissipated in mechanical frustration on the 20 floors of our building in New York was enormous, and it is still excessive. And the old ways were also frightfully expensive in terms of overtime costs in both the editorial and production areas.

The first working component of our new system was the Copy Processor, consisting of two IBM 360/30 computers--now being replaced with 360/40's--along with software of our own design. Words coming out of the editor's typewriters for all our magazines and books now enter this system and are printed out in the correct column width for each publication, automatically hyphenated, justified, and counted. Each proposed article is held in disc storage. As the story goes through editing and rewriting cycles, only the changed lines need to be retyped, with the rest called up from the computer memory.

When the story is released for typesetting, the computer transmits tape by wire to Chicago, where it drives automated linotype machines. However, the rate of 5 to 10 characters per second for typesetting will become more like 300 characters per second when we start full production use of our RCA Videocomp, a cathode ray tube that generates type. Although it has not yet had such use, we are already debugging our second-generation Videocomp machine and its associated equipment; already we have dozens of type fonts stored in its memory. Since each character is formed by a large number of fine parallel lines, which are actually computer-generated strokes of variable length, it becomes possible for an art director to add or subtract bars from characters, and thus create new type fonts or alter old ones. The computer can also help achieve artistic effects by making characters taller without making them wider, or wider without making them taller. We have come to call this "rubberized type".

Having helped our text people in this way, we feel we also owe our art directors something in the way of new technology. You may have seen an art director at work, pushing transparencies around on a light table while he sketched layouts. After three hours hunched over the table, he was often no closer to actually seeing his creation than the scratchy drawings on his pad. Several hours later, the pictures would bounce back from the photo lab. He would then spend more hours in the photostat room, after which he would go to work with scissors and paste pot for a full-size look at what he had in mind--except that it was a black and white look while the actual feature would be in color.

We now have a newly-designed layout machine that is aimed at eliminating much of this sort of hemming and hawing and wheel-spinning. It will display multiple pictures in full color on a *life-size* screen, allow the art director to move them around, trim and crop them, or change their size. He can throw in gibberish type and when everything is arranged to his satisfaction, he can push a button and get a black and white print in two minutes. We are still having a little trouble with the layout machine, possibly because an art director is more finicky than an editor about the tone and color values he would like to see. He wants to judge these against the white background of the page, but the present model of the layout machine seems incapable of generating white space satisfactorily. That may mean it must go back to the drawing board.

Another device being developed is an automatic page combiner, which puts words and pictures together into their actual format.

For many years we have had an electronic color scanner, with a built-in analog computer. This machine takes a full color transparency, "reads," and records on film the components of the three primary colors, and even produces a black component on a fourth film--even though pure black rarely occurs in nature and never in a color photograph. The scanner, however, goes beyond recording actual color; it can be programmed to make color "corrections" which represent, in a sense, the difference between the color values of photographs and the reflective colors of printing.

At the end of the pre-press line is our payoff, the photosensitive nylon printing plate. A nylon blank can absorb information from incoming film and be ready for the press in 40 minutes, as against the 12 to 20 hours normally required for engraving a set of color plates by the old method of chemically etching metal. A further advantage is that nylon, as a precision plate, requires a substantially shorter time for the adjusting and levelling process known as "press makeready." Even though we are somewhat locked into the older methods by substantial capital investments, we are producing the nylon plates as fast as we can, and are now equipping a newly-built plant in Puerto Rico to make thousands of these light-sensitive nylon plates--or, as we call them, *Tilon* plates--for *TIME*-nylon.

Also getting an important share of our attention is the tail end of the magazine line, the "post-press" area, where there is a crying need for new technology and methodology. We need an automated system for the storage, handling, collating, and routing of the sets of pages--which we call "signatures"--that come off the presses. This system must be faster and better, and require handling by far fewer people. Some intimation of the problem involved here can come from the fact that, at times, there are as many as *200 different* editions of LIFE in a single week, counting all the variations in advertising for different regions, market areas, and test markets, along with a great many of their combinations and permutations. In most cases, the changes in advertising pages require change in page layout as well; this accounts for the use of both numbering and lettering of pages that you may have seen in copies of *TIME* or *LIFE.*

We have been working--not too successfully so far--on what you may regard as control systems in trying to determine the optimum placement of pages on the presses, in order to minimize press stoppages. A further--and much more minor--complication rests in the fact that some parts of a magazine are printed in advance before the rest of the issue, in what is known as an "early form."

Another objective of a post-press system is to incorporate the initial sorting of magazines for Post Office routing, this being a logical corollary to the fact that the variations in advertising content of the magazine usually follow geographical lines.

I mentioned the Post Office service earlier as a major variable that affects our distribution planning. The fact is, however, that we enjoy a unique and mutually profitable relationship with the Post Office Department, and we do everything we can to keep it that way. It is no secret, however, that there is an inevitable long-term need for more modern and automated postal operations, if they are to handle efficiently the millions of tons and billions of pieces of mail in their charge. The Zip Code--or any other system--will be effective only when most of the slow hand work has been eliminated. This is a problem worthy of someone's best attention and efforts.

There are other things in prospect in graphic arts technology--portable typewriters that can produce magnetic tape and hook into ordinary phone lines, suitcase photodeveloping laboratories, use of satellites for transmitting pictures with high resolution over any terrestrial distance, and the technology of printing paper, in which we are intimately and deeply involved.

In summary, I would like to try to fulfill, in part at least, the promise I made earlier of suggesting some of the problems in our industry that might be the subject of control theory or, even more happily, control application.

I indicated earlier that the editorial processes really did not appear to be susceptible to rigid control. But much of what I have described as our pre-press system actually applies to some of those editorial processes. And there are others that suggest themselves, as well. What about, for example, the deployment of correspondents? With the coming of supersonic transport, and perhaps an eventual 2000-mile-per-hour plane, will it be necessary to have men permanently stationed in Lagos, Nairobi, New Delhi, or even Saigon?

And at the risk of treading on some editorial toes, what about the evaluation of sources of news and information--can they not be subject to more precise measurement? Or even the evaluation of sensory, or first-person, on-the-scene reporting, as against reporting through interviews with various experts or others who may or may not have been on the scene?

I think my neck is out far enough on that score, so I hasten to pull it back. It is perhaps impossible to get a sense of sacredness with which we regard editorial expertise and prerogatives at *TIME*, Inc., until one has lived with it for a period of years.

An area that should certainly lend itself to control is that of manufacturing and processing our physical products. That is what I have been describing through much of this talk, but we realize that we are making only a bare beginning, and that what we are now doing can certainly be greatly improved and made far more extensive. These processes, of course, impinge on such fields as general manufacturing and transportation that you are hearing about in these sessions from far more competent witnesses than myself.

The most valuable contribution that control theory might make to our business may be in the value rating of various forms of advertising and of the specific media that carry that advertising. Much of the data relating to advertising today is confined simply to the numbers of people or households potentially exposed to those advertising messages--often based simply on whether a newspaper or magazine is delivered to the household or whether a television set is turned on. Far too little is known about the actual observation and readership of advertising, about its effect and influence on members of the audience, and about the product-purchase behavior of the people reached.

All these, it seems to me, are elements of our society and our economy to which control theory can one day make a major contribution. When that time comes, I hope only that the representatives of the various industries affected will not be so hardened and fossilized as to reject your overtures. Those who do are certain to be the losers. Now that you at NASA have sent men to the moon, the choice becomes one of watching the stardust with you or eating your dust when we are left behind.

One is reminded of the woman who was supposed to have gushed at Carlyle, "Mr. Carlyle, I accept the universe", and the historian replied dryly, "Madame, you'd better."

DISCUSSION OF HALLENBECK PAPER

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I want to furnish a more appropriate pedigree for opening the discussion of John Hallenbeck's paper. I grew up to the smell of printing presses because my father was a long-time journalist, and I saw the communications field from the wrong side for many, many years. Thus, when it was proposed that communications be the subject of one of our sessions, I naturally thought it very appropriate.

We must look at the mass production of printed communications from the standpoints of what we, as systems and control people, can offer to it; and conversely, what the experience in this type of a situation has to say to us regarding similar situations.

I think that the founders of *TIME Magazine* in viewing their primary mission as a transfer of information from mind to mind -- as distinguished from simply producing printed matter and parlaying around signals from here to there -- established a most appropriate context for our discussion of communications. In my opinion, a very important element in modern communication has been left out in bypassing some interesting philosophical and psychological developments of the last century. For example, the American philosopher, Charles Sanders Peirce, was one of the founders of what he called *semiotics* or the theory of signs. The logical idea of a sign was that it was some type of mark (symbolic, graphic, or iconic in character), which was used by a human being with reference to a specific designatum (a specific object, idea, or image) in his attempt to convey to another human mind (or perhaps his own mind at a later time) an image that bore some relationship to the original designatum. Peirce saw this very graphically as a relationship in which the original object or designatum bore a relationship to the user and to a sign in such a way that, when the sign is observed or heard by the receiver, the designatum is recreated inside the other person's mind. Nowadays we seem to be preoccupied with the business of moving these signs about - in material and energetic forms - despite the fact that Briton Hadden and Henry Luce more incisively conceived that the signs themselves serve only to transfer an idea (or designatum) from one mind to another mind.

My reason for mentioning all this is that I think as Control Types we have much to learn from the experience of the mass production of journalistic media distributed to many millions of people on a very regular basis on very tight schedules. We have much to learn about how far into this end of the system we can reach and still contribute as control scientists and practitioners. This was the closing context of John Hallenbeck's paper; namely, that the reference position of most of the creative people, the journalists, the artists, the people who evoke these signs and begin this process, is basically humanistic. It is basically a random, subjective, artistic, free-wheeling, creative process; and it seems to be operating in contradistinction to many circumstances associated with control.

Now, as to the problem of taking the sign from the creator and originator to the receiver who reabsorbs it, John Hallenbeck has pointed out the natural interface that exists between the production process itself, the manufacturing of these signals and signs in print, together with the mass transport and distribution of the final printed material versus the communication of the energy-bearing signals - those information bearing energetic signals that can indeed transmit much of this same information. The news media, *Time Inc.,* in particular, have explored many of the obvious and naturally occurring ways in which this can be done.

Hallenbeck seems to take a most unsanguine view of a situation which, I think, most of us have presumed would occur very quickly; namely, that the printed word and the printed picture on paper would disappear rather quickly and make way for the graphic display on a suitable electronic video device. From the standpoint of the communication engineer, the technology of inexpensive home displays is not too far in the future. Certainly, before the year 2000 we would predict extinction of the printed graphic form, so that if there is some impediment, if there is, in fact, a delay or a failure to adopt such means, it could well be that there is some systematic defect, something lacking, in this form of communication.

There is yet another systemic aspect which I think Hallenbeck played down; namely, that when you see information in the journalistic press, you're seeing information from the "front line", so to speak. I mean the front line of information theory in the sense that things are not news if they can be anticipated and predicted. Thus, the task of journalistic enterprise is to convey the unexpected, the unpredictable; this implies a necessarily quick communication of information: thus, the concept of the "scoop."

Hallenbeck failed to mention that the time between the wrapping up of a typical issue of *Time Magazine* and the moment the magazine actually is read by people in their houses and on the newsstands is essentially 24 hours. He gave us such a good description of the mechanical process that it's possible for us to imagine the enormous amount of information processing and the enormous amount of decision-making that has to go on in this very short time. It seems to me that there is much to be learned from this type of experience that can be applied to the much broader question of distributing essential information in printed and other forms in connection with normal engineering and scientific activities. All of us have suffered greatly under the overwhelming weight of a truly obsolete system of information reporting in the scientific and technological area. Frequently, the information we need comes to us long after the time that we could best use it. We are completely destroying the engine which is producing this information by swamping it completely and by making selectivity virtually impossible, so that I think again that here is another area where, as technologists, we can profitably interact with this other industry to try to find some lessons and answers for ourselves.

Relative to the matter of how an industry with a huge capital investment goes about exploiting new technology -- again the situation of *TIME, Inc.,* is very typical of this kind of situation -- there is involved a very large investment with a very narrow timetable for getting new processes into action. There is always the risk in such a situation that we will suboptimize continuously and endlessly in such a way that we may find ourselves at the end of some long chain with a dodo, an extinct monster. We may suddenly realize that we have incrementally adapted our machines to changing technology, but that, in fact, the entire system we have constructed may be obsolete.

We seem to operate upon the naive faith that competition is sufficient to force technological progress. This point was raised in an earlier discussion; namely, that any one producer of petrochemicals has plenty of competitors to give it a workout. But this is only partly true in the journalistic area. There's no question that *TIME, Inc.,* just barely has competitors if they do at all. The *New York Times* certainly has now gotten itself into a situation in which it has no real competitors in the area within which it works. Here again there is this potential threat of obsolescence due to the continuous application of incremental technology, of modest improvements as opposed to reshapping the entire system in some bold way, like Briton Hadden's and Henry Luce's original mission.

I think this involves not only a difference in outlook, but also the recognition of two types of technological innovation. There is the kind of innovation that occurs very gradually as a steady improvement, and there's the kind, such as Gutenberg's and Mergenthaler's; namely, a complete discontinuity -- something entirely different becomes possible. Whenever this happens, the equilibrium is shifted dramatically. It cannot be treated as an incremental situation.

A point of economics that didn't get raised is, I know, evanescent in the *TIME, Inc.,* operation: this business of collaboration versus competition. It's extremely important in the issue of transportation versus communication because, if it is possible to arrange transport and production facilities in such a way that they can handle several different products, certain benefits ensue. Moreover, it will shift the equilibrium of production and transportation and communication in a different direction. However, there are also certain liabilities associated with this. I was always amused that the Sears Roebuck and Montgomery Ward catalogs have been printed by the same firm almost from the founding of the companies; that the same publisher actually produced the catalogs of great rivals, direct competitors. This observation opens up an issue which may be more than a purely economic issue. It may be a social issue because, if the production process, the communication process, and the transportation process, get congested as a result of competitive economics, then perhaps collaborative economics has to be imposed.

Finally, a most important point that Hallenbeck raised at the head and tail ends of this journalistic process was the essential selectivity involved. Some scientists and engineers are not sanguine about the idea of home graphic displays replacing the printed magazines because it imposes restrictions on the ability of the receiver to select. It poses tremendous technological problems if you allow him the choice in selection that he now has. Today, he can select among many magazines. (My family, for example, tries to restrict the number of these magazines to about ten on a weekly or bi-weekly basis, one-tenth of which we will collectively read.) The selectivity within any one magazine is again fractional; but it *is* random. We invariably receive information unexpectedly from some article we happen to read which we didn't set out to choose to read. Is this an essential feature of good communication?

Hallenbeck emphasized the selectivity at the head end of the problem. In other words, can you replace the independent correspondents? Can you get rid of some of the foreign correspondents and use the wire services and so forth? The argument that has to be raised again is that if you allow a mechanical system or some established system to pre-empt the selective process, then you can very well predict, I think, the long-term consequences that will ensue. In short, what price are we paying, versus what benefits received, for the randomness in selectivity that some of our naturally evolved systems have given us?

FLOOR DISCUSSION

Dr. H. Kushner: I'd like to ask a question about a slightly different problem which one could conceive as a control problem. This is the effect of inadequate reporting of news and future developments of the news itself. For example, a reporter or news photographer or TV cameraman in a certain situation may ask people questions or may provoke a demonstration of one sort or another which he then reports. This may lead to other things. On the other hand, of course, one sometimes has rather blatant editorialism. This leads, of course, to attitudes which then lead to developments in news, and so forth. Generally, I suppose, even honest, conscientious reporters may well affect the outcome of things just because they're there. The fact that they're only in one place, you see, might give the impression that the thing that has happened is a thing that happens in the place that they're in. Now, this is reported honestly or dishonestly; usually, of course, there isn't time to be completely honest. The question is: What effect has this on development of the news itself? This is a type of feedback situation, and I wonder whether either speaker or their colleagues could say this is really is an important thing. I would think that if this really unimportant, perhaps a large part of the news as reported is unimportant in itself.

Mr. Hallenbeck: I think it's very important. Obviously, you were watching your television set during the fiasco in Chicago.* I'm sure that's what you're thinking about, and I watched my television set during that fiasco, too. There is no question but what a reporter is zeroed in on a particular area. However, that doesn't excuse the medium. The medium certainly has the opportunity to do all of that filtering and looking over of the information. I think very often we are misled along with television. I think they are misled much more often than we are because their communication process is instantaneous. They do not have the filtering process that we have. They show what they see at a particular time at a particular place, and they pass it on to you. You might be getting entirely the wrong opinion of the seriousness of the situation or what's happening.

I think that in this particular case we may have been misled a little, too; but I don't think we were as guilty -- and I'm not trying to defend one versus the other -- as television because we had an opportunity to take one man's opinion as against another's and as against television before we closed that issue and passed the word along.

Professor Paynter: Could I just mention there seem to be two things there, both relative to the human beings initiating or originating the communication. One is their immediacy in space, whether they are themselves witnesses to the events; the second thing is the one Hallenbeck just spoke of, the gain or loss that occurs if there's some time delay. It may be a gain or a loss; it's debatable, but *it* is a difference. Again, if you go back to the charting founders of *TIME, The Weekly News Magazine,* it is certainly clear that there was a presumption that somehow a week-long time constant applied as a filter has some benefit or at least some marketability. It has some benefit, and I think that is an important point. I think the great mistake in the early days of television was to believe that the man on the camera wasn't usurping a right, because what he looks at, and the way he focuses that camera, are definitely creating a stream of information which, in turn, creates images in the receiving mind. There was some delay in the use of tapes and there was some pre-emptive right exercised by some networks to use or not to use certain tapes; but by and large, the live television is a unique phenomenon in man's experience in the sense that we are receiving these instantaneous impressions and some of them are unerasable. Certainly the shooting of Oswald by Ruby (presumably) -- we thought we saw it. Here were 18 million people witnessing, in real time, its a murder of a public figure. That is a traumatic situation -- I know it was traumatic for my children to see it. It was a very unusual situation. I do think that there are important elements here that aren't well understood.

Mr. Hallenbeck: I think Harold was addressing himself to the question of the feedback that you get from the information you receive from the various news media.

Professor Paynter: That we receive or that who receives? Who gets the feedback?

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*Editor's note: Reference to the disturbances during the Democratic Convention held in Chicago, August 1968.

Dr. Peter Falb: That we all receive by the reading of the newspapers, looking at the TV, and particularly to the question of the noise in that channel. Some of the noise which is generated through reporting, bias, inaccuracy, and so forth; and this has the power really to make events. I mean I think that was his point -- that you must act on the information that's available to you, and if it's inaccurate or biased, then your actions will be incorrect.

Professor Paynter: Right. Well, Peter, on that point, I think the position of *TIME,* in particular, has been that it is their privilege to editorialize in the news, to coin new words, and to coin a whole new style. The presumption was that this was beneficial; that it somehow provoked some good because the spurious, noisy, random, daily feedback processes presumably don't have adequate editorial and control functions.

Mr. Harlan Anderson: I think I have an example in our own company of what's been happening not only in the printed products but also television. Recently I was out at our television station in San Diego, which is an NBC affiliate, where they were faced with a problem of how to cover a local Black Power group that was going to have what they described in the advanced billing as a "mass rally." If we had covered that from one angle; namely, the one that the Black Power group wanted us to cover it from, it might really have been a mass rally. But we covered it from the standpoint of how poorly it had lived up to its advanced billing; that there weren't nearly as many people, as many national leaders coming to speak about Black Power, and this sort of thing. What I'm saying is that the television medium is beginning to use more interpretive journalism. It's having to take its responsibility more seriously in what they present to the viewers.

In the early days of television you set up a camera and you had the illusion that by total objectivity you could cover exactly what was happening. It was the fact and there was no room for error in judgment or interpretation. That was a fallacy. Judgment and interpretation is a necessary part of that medium, just as it's been a necessary part of our medium for a long time.

Professor Paynter: In fairness to history, we have the famous business of the Kennedy-Nixon debate -- I don't think anybody realized how unmerciful the television lighting system was to Richard Nixon's five o'clock shadow as opposed to Kennedy, whose hair structure was such that it didn't respond to the lights!

Dr. Gifford Ewing: I'd like to ask Mr. Hallenbeck a question. It's an involved question. How much information is there in an issue of *TIME?* The reason that I don't watch television myself is that it is a sequential access operation; I have to look at Mickey Mouse and advertisements for this and that soup in order to get to the thing I want to see. Whereas, if I read *TIME Magazine* -- I hate to say this out loud -- but I can skip all the advertising and go to the thing I want to see. I don't see any inherent reason why a news distribution system can't be a random access device that can be challenged by the viewer. We do this on computers all the time. We have a big computer at M.I.T. (Mass.) and we have a keyboard at Woods Hole (Mass.). We can call up the computer and ask it all kinds of stuff, including things that are in its magnetic memory -- and it has a pretty darn big memory. So, suppose that I were to design my own television system; it would be a system where I could call for exactly the information that I want or the field of information that I want or any degree of processing I want. I might ask for shows or news suitable for children if I wanted. This machine could censor the news or filter the news and give it to me promptly and directly without having to sit around watching a lot of boring junk.

My question is -- and it's a technical one -- what are we really talking about? In a technical sense -- like Professor Weaver and Dr. Shannon -- how many bits of information are there on a page of *TIME* or an issue of *TIME?* Is it astronomical or is it conceivably within such bounds that we could store all the news that's being published, all the Bunny Club news, everything in one central place where anybody could challenge it? What are we talking about? How much information is there in an issue of *TIME?*

Mr. Hallenbeck: Before I answer your question – which I'm not going to do – certainly we have addressed ourselves to this problem, and I don't think there's any question but that it is conceivable. I merely said I thought that the printed word was here to stay for the foreseeable future. I think even if we had the kind of device you're talking about, it would only suit itself to certain individuals. Some people are always going to want the filtering method done for them. So, therefore, I think that what you're saying, what you're asking for is going to come to pass. No question about it. It's a question of timing, the demand for it, the demand for it not only from the individual, but from the masses.

Dr. Ewing: I don't really quite understand what you're saying because a television set is now a random access device, but a severely limited one. You can choose the channel and you can choose the time of day you look at it or you can choose to turn it off. Those are the three options which you have; and certainly in the stockbroker's office you don't sit and watch a tape anymore. You ask a computer in New York what happened and, boom, you get vastly more information back right away than you want to know. So this thing, I should think, could be programmed into the news media quite as well as it can in the stockbroker's office.

Mr. Hallenbeck: I think it can. I think it can and will come to pass. I do not think, though, it's quite as simple as that. We have done some work on that, as Harlan Anderson will explain.

Mr. Harlan Anderson: The words are quite simple; the pictures are very complex. We have done something on an experimental basis a little like what you're asking here. We have taken, I believe it was a year's issues of the words in *TIME Magazine,* put them in a computer memory -- a time-shared computer. (This was a joint program with IBM.) We could query this data base, if you want, in a completely unstructured way. That is, we didn't have to know what issue we wanted to look at. We could use key words, in information retrieval parlance, and the computer would look through and find what articles, what issues had those words in them and direct you to them. You could look at them either through a teletypewriter or you could go look at the magazine itself. So, the amount of information, if you leave out pictures, is definitely finite, definitely within the bounds of computer memory. There's no problem there at all for *TIME Magazine.*

Dr. Ewing: Where can I buy one of these things?

Mr. Anderson: You couldn't afford the one that we used experimentally. We found it even too expensive to continue as a long-term research project. We got the answer we were looking for -- how well can a computer do in finding the part of the magazine that answers the question we had in mind? That it could do very well when you use the key word -- technique. The next step, though, if you want all the news from everybody's viewpoint, including the *New York Times, Newsweek,* and everybody else's publication, would exceed the capacity of computer memories that I know about today. Now, if you put into it the problem of pictures and you try to convert those to digital images or you try and rig up somethirig like the CIA's sytem for handling pictures, you're in a different league of complexity. If you add color, which is a very important part of our business, and you add to that the ability of individual users to get access over unique communication lines for their own purposes, like those who use telephone lines to computers today, the problem becomes enormous.

There is, I think, an intermediate solution that is less satisfying that what you were asking for, but one more likely to come in the near future. This is some combination of broadband communication lines, such as those used in the Community Antenna Television System, where they talk in terms of 100 television programs over one piece of cable. The cost for you to get that into your home is around five dollars a month, which is in the right economic ballpark. But there aren't that many television programs today; so that some of these extra channels will be used for services of the kind you talked about. If you broadcast information over these cables and couple it with an unattended video recording in the home, so that the evening news can be recorded at any time during the day; you can look at it whenever you wish without having to wade through Mickey Mouse and everything else. I think that a combination of broadband cables and in-house recording of things that you have selected for your purpose and for the time you want to see it, is more likely in the near-term future than individual interrogation of a data bank.

BIOLOGICAL CYBERNETICS

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THE CONTROL CONCEPT

Cybernetics was defined by Norbert Wiener as the "science of control and communication in animals and machines." It is in this area of bioengineering that some of the most exciting scientific contributions have developed. Of all biological control systems, the neurological control systems most often conform to such important systems analysis requirements as unidirectional transmission between causally related lumped-parameter elements. By this we mean that information passes unidirectionally, undisturbed by backward interaction, from one block to the next; and that each block in a block diagram represents an operation or mathematical transformation that can be considered as being located at a node or in one point, that is, *lumped,* rather than spread over real physical dimension.

A classical example of a neurological control system is the pupillary servomechanism. Here the feedback path can be experimentally opened, using either optical or electronic techniques. Both linear-transfer-function analysis, including stability, oscillations, and noise (as well as the sophisticated and nonlinear engineering theory such as Wiener-G functional analysis), have been successfully applied. Figure 1 shows a Nyquist diagram of the normal human pupillary system, constructed for experimental operating conditions. Figure 2 shows some ensemble statistical behavior which, together with earlier studies, leads to the model shown in Figure 3. Here we see a multiblock nonlinear statistical engineering model of a complex biological servomechanism. Much of the knowledge in engineering control theory could be brought to bear on this one relatively primitive neurological reflex. As will be explained in a later discussion on education, the requirements for advanced engineering science in biological applications is one of the most important educational roles of bio-engineering. Exciting and intellectually substantial thesis problems for engineering students can be generated.

Many other neurological reflex systems have also been studied; in particular, those controlling the movement of the eyeball in either versional tracking movements or vergence movements have resulted in interesting applications of engineering theory. The manual control field has been similarly developed in a number of directions, in addition to aiding in the design of airplanes and space vehicles. Neurological models of the control elements and the neuromuscular and sensory elements of the hand movement system have been used to attempt a rational-parameter, non-linear model of the system. The eye-and-hand-movement system exhibits characteristics such as discontinuous or sampled data operation and predictive ability for repetitive input signals, which are quite different from the noisy unpredictive, non-linear pupillary system.

INFORMATION THEORY

The nervous system is also amenable to analysis in terms of information theory. An interesting example is the use of Claude Shannon's information theory to analyze the nerve impulse code in the simple crayfish tail light receptor system. Figure 4 shows an example of an auto- and cross-correlation study which allows the information rate of three bits per second to be experimentally demonstrated by defining certain stochastic relationships between the nerve impulse trains. The lower two diagrams in Figure 4 show the interval histograms of the two photosensitive fibers, F_1 and F_2, carrying the same information concerning the light stimulation. These and the middle two diagrams or autocorrelation functions, F_1F_2, show the nerve impulse trains to be quasi-periodic sequences. The upper diagram shows the cross-correlation, F_1F_2, between the impulse trains in the two fibers. This is random, lying within the two standard deviation limits, and demonstrates absence of impulse interval correlation between the two fibers. The "Nerve Impulse Code" thus is suggested to be an average frequency code transmitting 3 bits/second, rather than a more precise interval pattern code transmitting 100 bits/second.

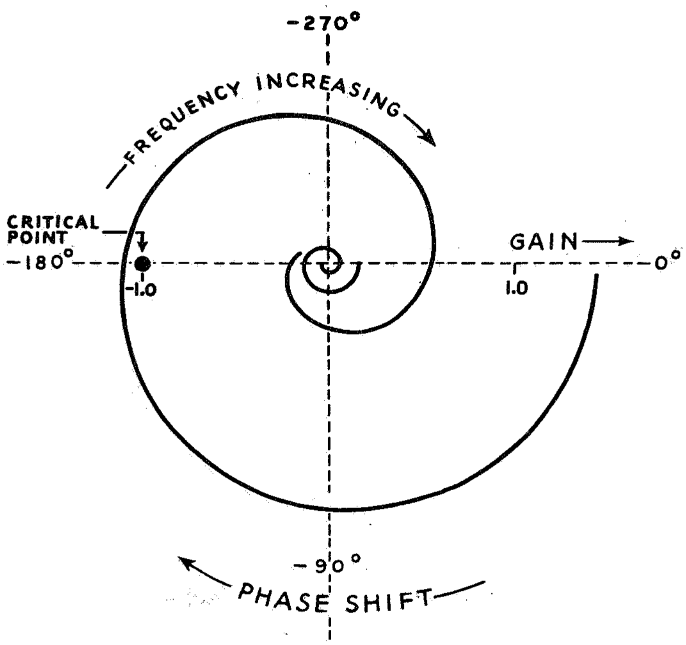


Figure 1 — Nyquist diagram of pupil response, a vector plot of gain and phase shift; scale of modulus and a few frequencies are indicated; curve is derived from fitted lines from gain and phase frequency-response graphs, while points are experimental.

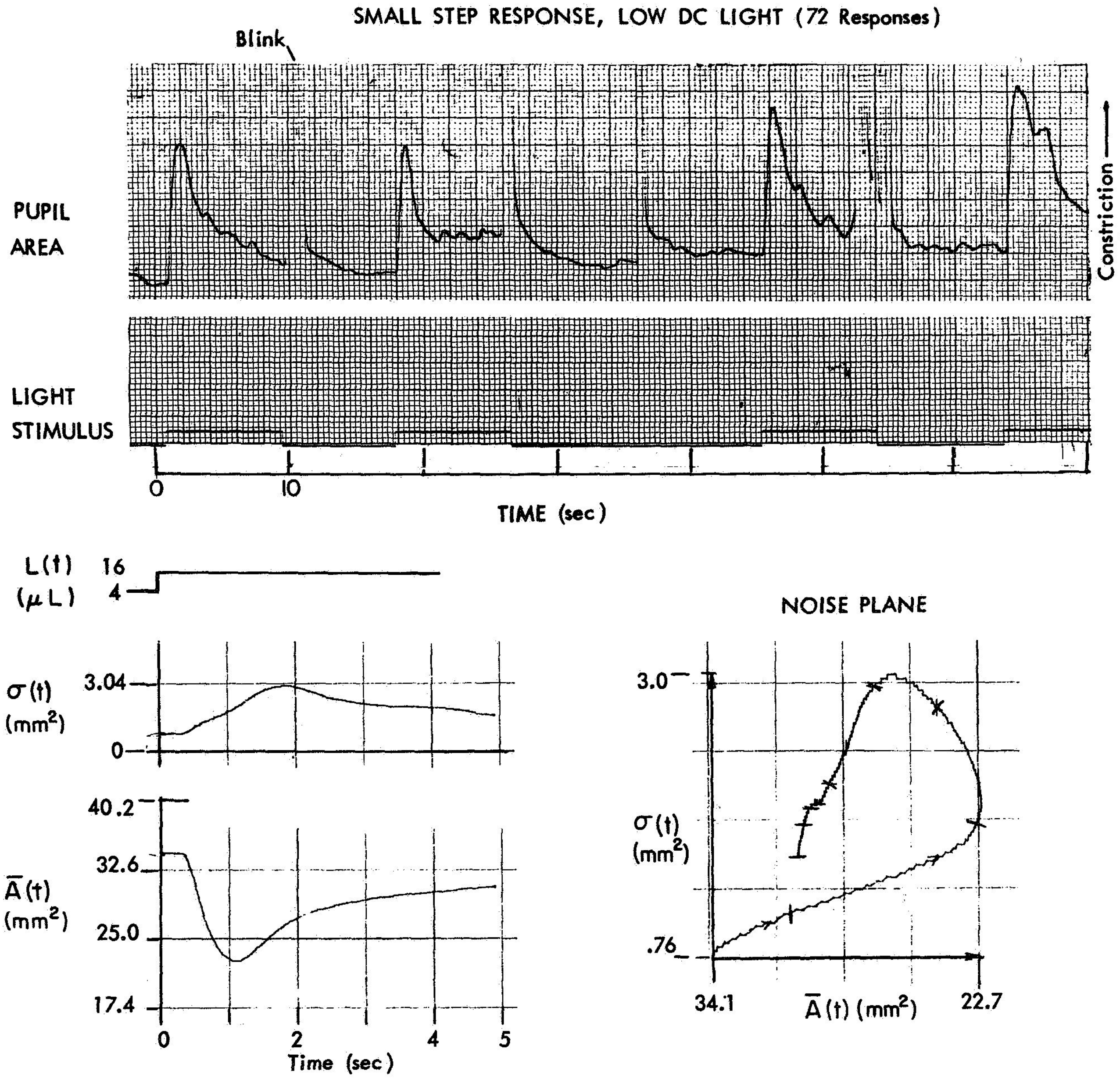


Figure 2 — Noise plane display of small step response, with low constant (DC) light level.

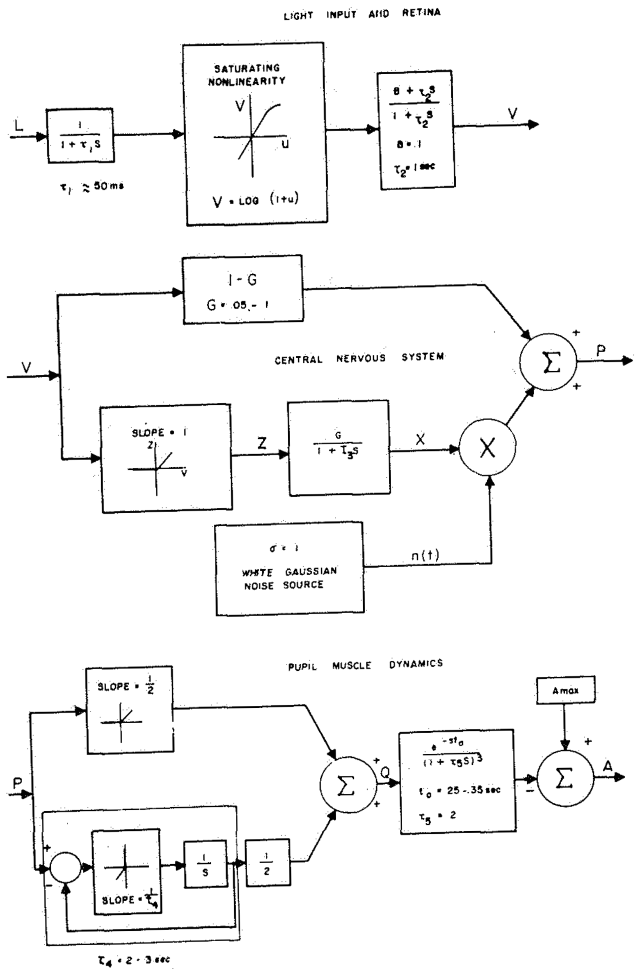


Figure 3 — A non-linear pupil model.

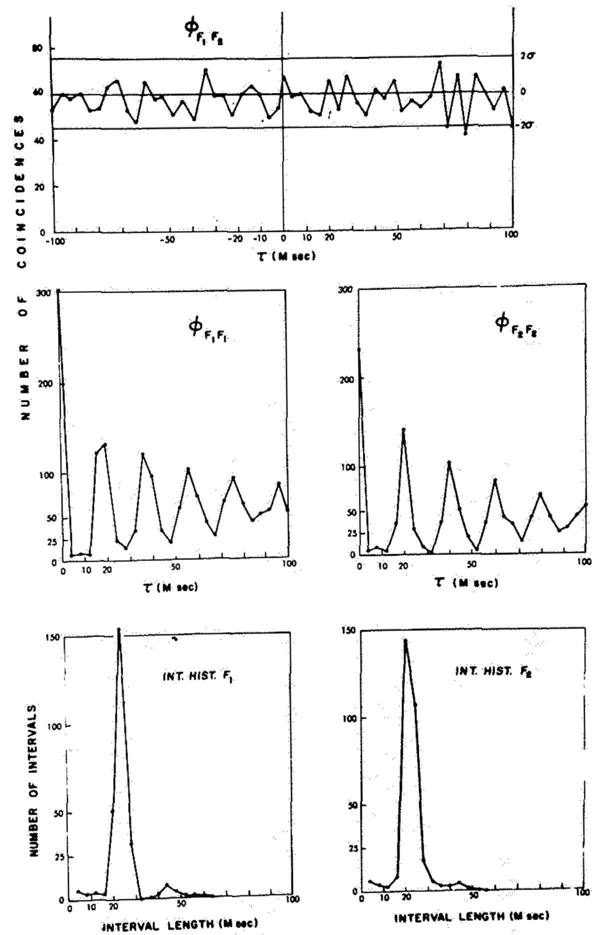


Figure 4 — Absence of correlation; periodic signals during light stimulation.

The general approach to the central nervous system, when considered as an assemblage of neurons performing logical operations, has been stimulated by the pioneering work of McCulloch and three of his students, Walter Pitts, Jerome Lettvin, and Patrick Wall. Their work on various portions of the nervous system acting as transformation operators or property filters is exemplified by work on the frog's retina (See Figure 5). This is an important, experimental illustration of cybernetics for bio-engineering, engineering science, and classical neurophysiology. More classical neurophysiologists, such as John Eccles, Ragnar Granit, and others, have become interested in the brain as a computer. Recent work on "anatomical transfer functions" for the cerebellum shows an extension of engineering science into the field of anatomical relationships.

PHYSIOLOGY, BIOPHYSICS, AND BIOCHEMISTRY

The systems approach has an important interface with analytical physiology both in the understanding of physiological control and in the development of formal mathematical engineering models. Of biological control systems, the cardiovascular system is one of the most important. It has many subtle features, such as distributed transmission line elements and complex mechanical constraints. Attinger, McDonald, and Noordergraff have studied a more realistic cardiovascular system modelled on the bases of real pulsatile flow, the branched arterial tree, the veins, and the heart as components in the entire cardiovascular system. Rideout has used the two-fluid scheme shown in Figure 6 for simulation of gas transport in blood and the perturbation method for study of dye flow dynamics, using a complex hybrid computer system in conjunction with his studies. Harris is interested in a systems identification method for determining parameters of central circulation from clinical indicator dilution curves in patients with intracardiac shunts. Figure 7 indicates the success of this parameter identification method. Warner is also involved with a similar type of parameter estimation from indicator dilution curves for circulation pattern under various stages of anesthesia with various drug effects. His aim is to reflect the response of the vascular system to demonstrate the role which different vascular beds have in the cardiovascular mixing process. Stacy, Coulter, and Peter have been studying power dissipation in vascular networks. These are based on measurements of arterio-venous pressure differences and flows in pulmonary and systemic vascular beds. Data are recorded on magnetic tape and processed using a LINC computer complex. Impedance and phase angle determinations show that mean power dissipation sometimes overestimates actual power dissipated. Energy cost of transport appears to be a very sensitive indicator of cardiovascular performance. Other studies produce sinusoidal oscillatory flows of blood in rigid cylindrical tubes and pressure gradients are obtained. Hydraulic impedance versus frequency curves for blood differ significantly from those of aqueous glycerol, and from predictions of Womersley's theory. Figure 8 indicates their results. These studies on the cardiovascular control indicate the complexity of this system, prospects for application of systems science to cardiovascular physiology and the importance of various engineering instrumentation and computation techniques in these studies.

The respiratory system begins to be involved as soon as one considers the cardiovascular system as, for example, illustrated in Figure 6. A review of the respiratory system modelling by Horgan starts with Grodin's classical work and reviews six recent papers studying the respiratory system including his own work. Stacy and Peters also have studied lung compliance as shown in Figure 9. Other interesting biocontrol systems are the endocrinological control system, the temperature control system, and fluid balance.

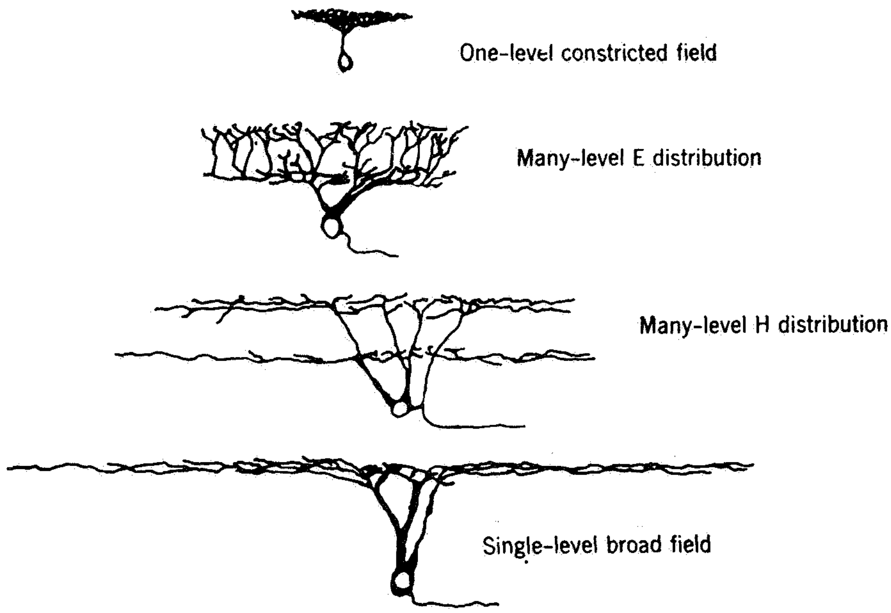


Figure 5 — "Lettvin operators" are neurological arrangements of ganglion cells, bipolar cells, photoreceptors, and horizontal connectives which can abstract a "property" of the retinal image and communicate the presence or absence of the property to the brain; four anatomical varieties of ganglion cell show structures conducive to performing four different "property filter" operations.

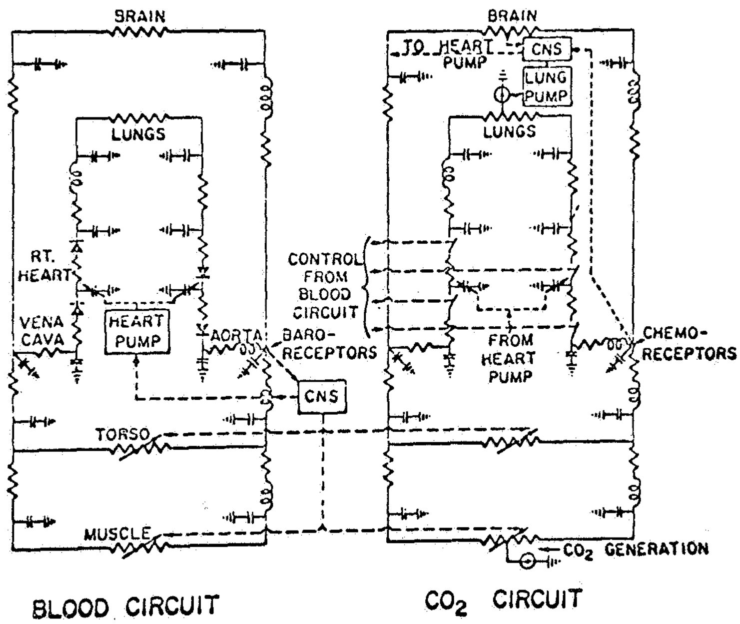


Figure 6 — Two-fluid scheme of simulation of gas transport in blood (Rideout).

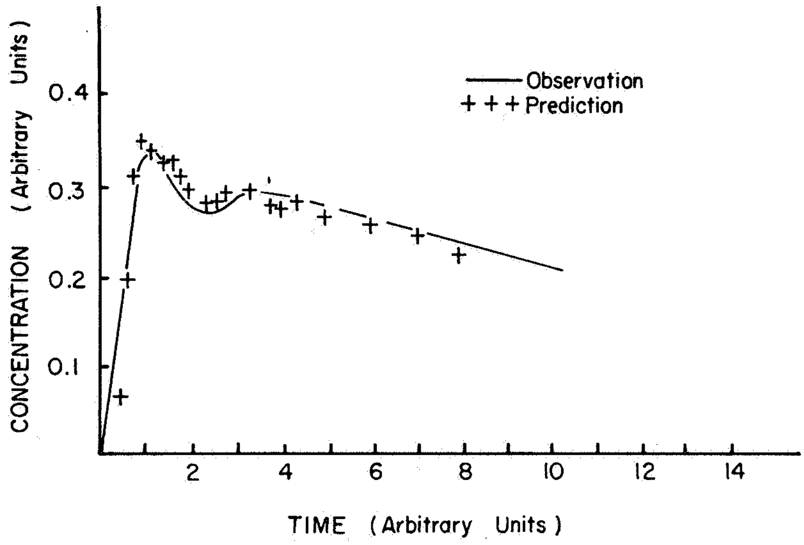


Figure 7 – Theoretical and observed indicator-dilution curves from a patient with an intraventricular shunt (Harris)

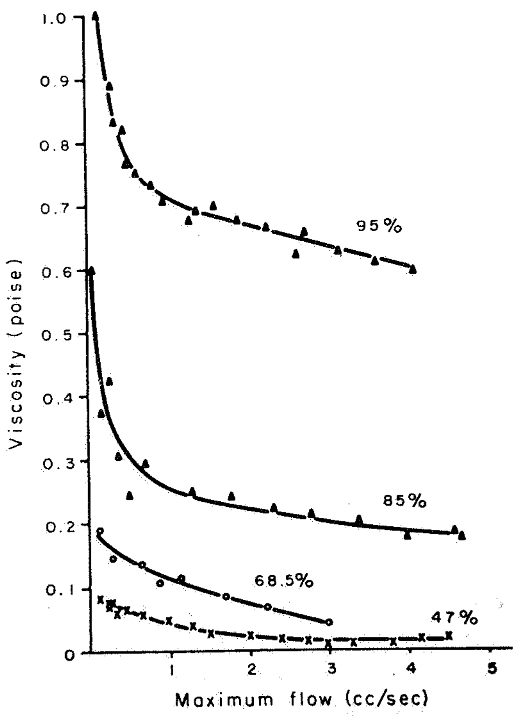


Figure 8 – Dynamic apparent viscosity of blood of different hematocrits, plotted against flow amplitude. Smooth curves have no theoretical significance (Stacy)

On the one hand physiology without biophysics and biochemistry remains largely engineering system science applied to biology; on the other hand, important interfaces exist between cybernetics and both biophysics and biochemistry. Even though biophysics and biochemistry represent analysis of elements of physiological systems, much of the research in these fields requires systems analysis to place it in proper perspective. Muscle and nerves are themselves complex systems and non-linear circuit models of muscle attempt to carry models beyond those proposed by such physiologists as Huxley and Wilkie by utilizing engineering analysis. In addition to modelling neurons from the point of view of their role as information operators, as illustrated by the McCulloch/Pitts neuron model discussed later in this section, there is also interest in modelling single neurons in terms of their membrane properties, as in the model of Geisler, the structure of which is illustrated in Figure 10. From this random process model is indicated the necessity for a very fast recovery function for neurons in the mammalian auditory system.

Biochemical systems relate closely to the endocrinological control as indicated by work by Finkelstein, Campbell, and Abbrecht in terms of pancreatic response and control of blood glucose level. A recent interesting article entitled, "Waveform Generation by Enzymatic Oscillators," by Chance and associates, relates to the chemical feedback mechanisms in glucose metabolism. Here we have an interaction between engineering theory and the metabolic machinery of the Cell. Figure 11 is a block diagram of the various cellular mechanisms involved in glucose metabolism with multiple feedback loops indicated. Biochemical control systems lead to interface between cybernetics and molecular biology. Here the term, the genetic "code," is obviously an attempt to make analogies with coding and information theory results of engineering communication science. Even more important advances will hopefully soon be made in developmental control and embryological mechanisms, so that this important theoretical scientific interface should be watched with great attention.

MEDICINE

The scientific aspects of medicine are just beginning to benefit from the systems approach. Many, if not most, diseases have pathophysiological mechanisms which might be classified not as a breakdown in single elements, but rather in the loss of control in proper operating interaction of a system of elements. This concept offers a long-range promise in the basic understanding of disease mechanisms.

The interface of systems science with biomathematics has developed into quite a vigorous one. Several training programs of bio-engineering cooperate with biomathematics programs. The importance of classicall applied mathematics and of statistics cannot be minimized and, the work of such people as Rashevsky, Landaw, and Bartholomay in further developing biomathematics programs related to bio-engineering has been an important influence; however, many feel that engineering mathematics is the exciting applied mathematics of the present day.

At this point, two important goals for bio-engineering should be identified. One is the conceptual insight into communication and control processes in biology utilizing the systems approach. The other is the conceptual insight into the basic nature of disease processes from the point of view of cybernetics. These two goals are suitable for focussing of attention for planning efforts or for closely watching the future development of bioengineering.

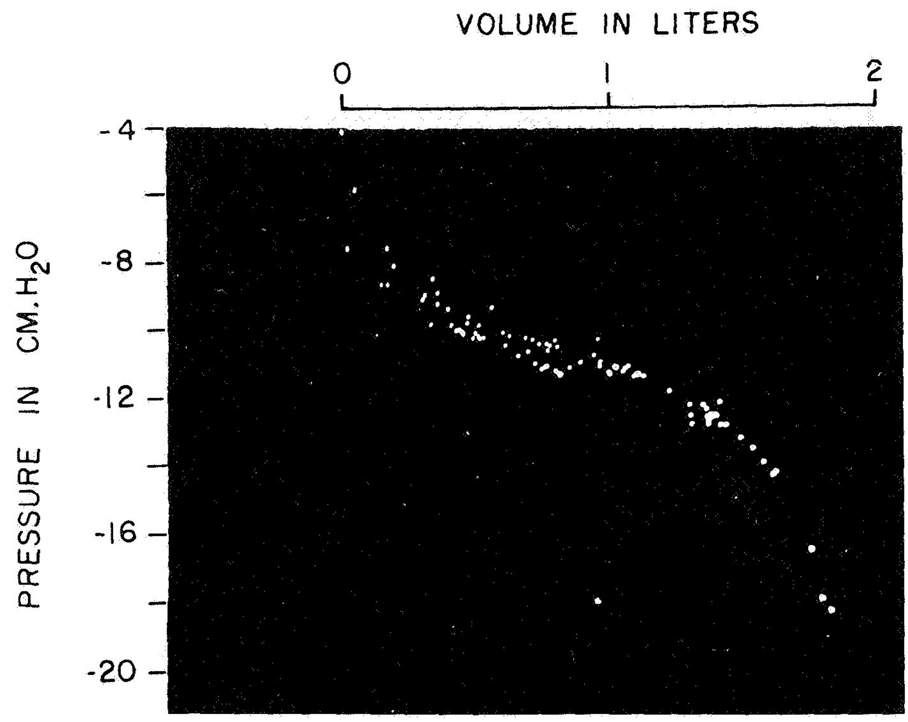


Figure 9 Compliance curve automatically determined by LINC III (Stacy)

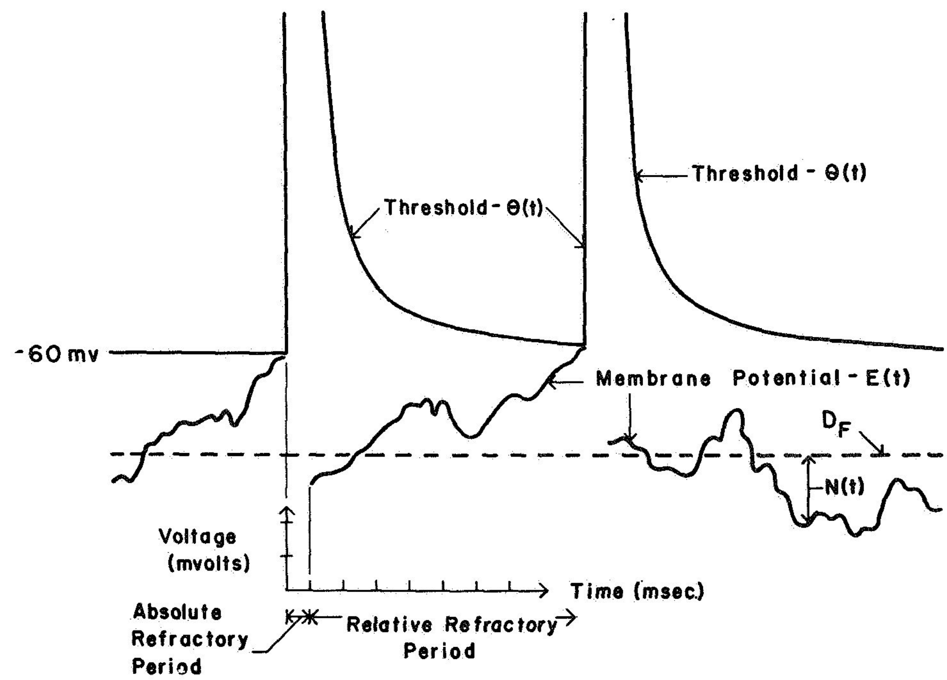
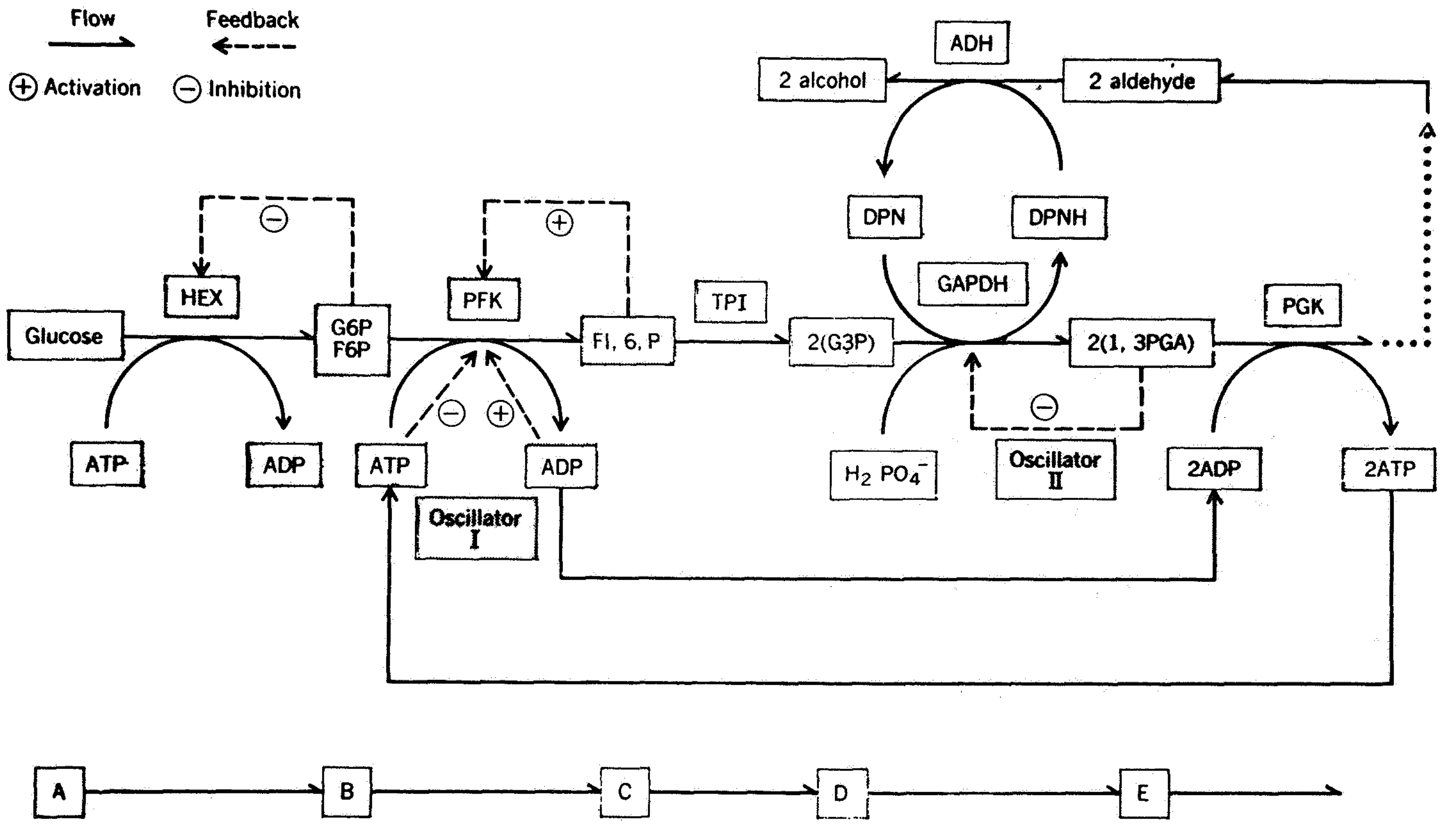


Figure 10 — Random-process model of a neuron (Geisler)



Chance, Pye, Higgins—Waveform generation by enzymatic oscillators

Figure 11 - Chemical feedback in glucose metabolism (Chance)

BIONICS: COMPUTER DESIGN AND PATTERN RECOGNITION.

Bionics, or, as Professor McCulloch prefers--*biomimetics*--has been defined by Steele as the utilization of principles of design of biological systems for the construction of man-made devices. One of the most exciting developments in this field occurred in middle 40s, when Von Neumann, Goldstine, Bigelow, and Burks utilized McCulloch-Pitts neurons to design the Institute for Advanced Study digital computer. McCulloch and Pitts had developed the formal neuron as a "poverty stricken" example abstracted from the richness of normal brain neurons, in order to analyze in terms of Boolean algebra the properties of networks of such neurons. Von Neumann, in carrying out the logical design of this digital computer in which logical design was separated in principle from hardware design, used McCulloch-Pitts neurons to draw his logical diagrams as shown in Figure 12. The names given to various portions of the computer such as the memory organ and the logical organ are other more intuitive examples of the application of principles of design of biological systems to the construction of an important artificial device. Other areas of importance in biomimetics are recent developments of artificial robots such as those designed to operate in lunar environments utilizing principles of postural and manual control, as elucidated in human engineering studies.

Another exciting bionics area is the development of artificial intelligence pattern-recognition devices for visual pattern recognition in the directions both of hardware devices and also of digital computers as exemplified by the artificial-intelligence programs for pattern recognition analysis of electrocardiograms. General features of pattern recognition now appear to be grouped in three problem areas as shown in Figure 13. First is the problem of the selection and measurement of properties of an event or object to be recognized. The sum total of these properties and their scale of measurements constitutes the reality of an event. Each event thus is transformed into a point in N-dimensional property space. If certain events occur repetitively and cluster in a particular region of this property space, they will be recognized as dissimilar. Another of the problems in building a self-adaptive or self-organizing pattern recognition device or program is to make appropriate decision rules for partitioning the space appropriately to create a taxonomy. The third problem area is the use of this categorized space or taxonomic classification for some purpose such as signal identification. This bionic pattern recognizer is a good example of the development of engineering design principles from analytical and experimental studies of principles of function of biological organisms.

EDUCATION IN THE HEALTH SCIENCES

At the present time, the medical world is in a crisis. Developments in mathematics, physics, and engineering sciences have outstripped the understanding of general practitioners, medical students, and even members of academic medical faculties. For this reason, such important institutions as the National Institutes of Health in Washington are turning increasing attention to the "continuing scientific development" of the medical scientist in terms of re-education of senior medical people, faculty personnel, who have already demonstrated creative ability in their own fields. For this re-education, bio-engineering, biomathematics, and physics loom large. The bio-engineering programs in some universities are already intimately related to these developments in medical education, and represent a national resource for such re-education.

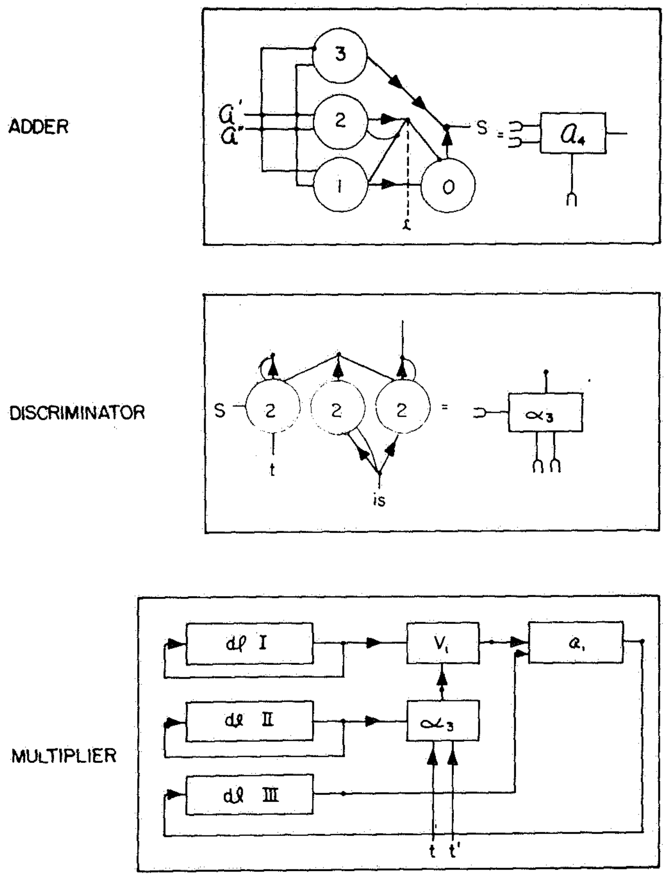


Figure 12 — Logical design of EDVAC computer elements using McCulloch-Pitts neurons from first draft of a report on the EDVAC by John Von Neumann, June 30, 1945; Contract No. W-670-ORD-4926, between the United States Army Ordnance Department and the University of Pennsylvania (Von Neumann)

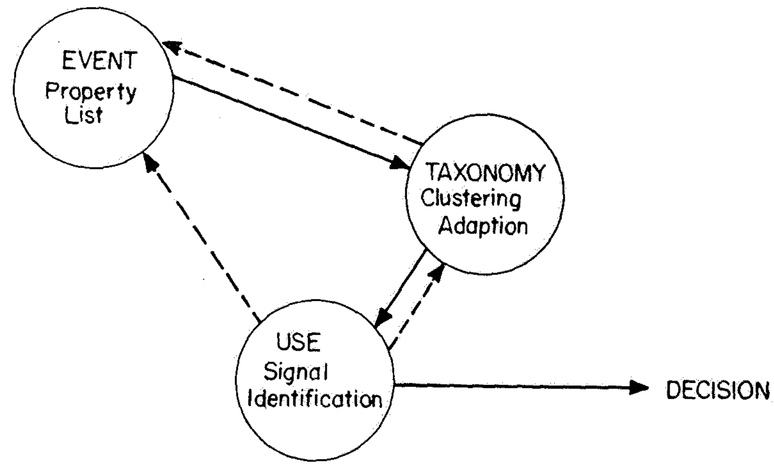


Figure 13 — General features of pattern recognition research (Stark)

It has now become apparent also that it is necessary to restructure the general process of medical education. Just as the Flexner report developed an undergraduate program preceding medical school and revolutionized and set the stage for the present situation, so too the studies by Brown, Dow, and Dickson may change the present status of the graduate education phase of medicine. If in 1900 it was important to introduce chemical science into medicine, so too in the 1970's it will be equally important to incorporate engineering system science into the medical curriculum. Bio-engineering, playing intellectually an essential role in physiological research and teaching, will already be present in the medical school curriculum and will be an excellent base upon which to build in two directions. The first direction is towards more graduate-level mathematics, engineering, and physics for medical students. The second direction is towards practical interaction with the technological world of instrumentation, computers, and systems science that will be the dominant influence in the delivery of medical and health services to patients in hospitals and in the community.

At the present time, bio-engineering has an exceedingly difficult educational task. Almost all programs are required to have three tracks in their educational curriculum. These are: (1) re-education of the biologist stressing background mathematics, physics, and engineering science; (2) education of the engineer in the basic principles of biology and the experimental approach to the richness and variety of biological systems; and (3) the bio-engineering subjects themselves, covering advances in the field over the past 15 years, now becoming semi-structured with the experience of many programs. These bio-engineering subjects, of course, require preliminary background in both biology and engineering.

There are also two levels of *graduate education* in the field of bio-engineering. At the first level the aim is to produce a bio-engineer capable of participating in an interdisciplinary team effort in some bio-engineering project. He might be a biologist or physician immersed in some problem area who wishes to obtain enough engineering background to be able to communicate with professional engineers. He might be an engineer who wishes to master only enough physiology background to be able to communicate effectively with the life scientist and is willing to depend upon them for definition of the problem area in either applied or basic research. A few programs have now developed at the Master's Degree level to produce individuals with this training; there is obviously a great need for such a person in increasing the technological level of the medical and health sciences.

Most of the programs have as their goal a Ph.D. student who will be able to serve as an independent scientist, either as a faculty member, or as a leader of a bio-engineering group in industry or in government. He must have enough biology background to be able to specify, define, and have good scientific intuition about a biological or medical problem area and, at the same time, have enough engineering background so that he is able to appreciate the ever-new developments in engineering theory and be fully up to par as a doctoral level engineer in applying engineering science to these problems. In short, he must be an independent scientist with excellent background in two quite different fields.

The difficulties of such programs are great. Edmonson has described one such program at the University of Michigan. An interesting suggestion is that of Otto Schmitt who proposed modular education wherein video tape lectures would be obtained from experts in specific areas. In this way, a group of people scattered throughout the country--a group that no one university could possibly collect--would be able to provide material for a solid program in bio-engineering.

Another solution to the problem of bio-engineering education,and one about which I am particularly enthusiastic, is the *undergraduate program* in bio-engineering. It seems quote possible to have a student major in engineering; in particular, for example, in electrical or information engineering, fully satisfying all engineering core requirements, his major requirements, and his engineering minor requirements. In addition, he could use his elective time to obtain all the biological and chemical background that would be required of a biology major or of a pre-medical student. Even in a rather rule-conscious state university, a capable student should be able to complete the bio-engineering program in the usual four years. Perhaps one should stress the need for that flexibility which would enable him to approach two different subjects, such as biology and engineering. For such a student, the bio-engineering graduate program will be relatively straightforward. He may use his time not to get biological background but to take more advanced biology graduate courses; similarly, if his engineering background obtained as an undergraduate makes unnecessary the engineering remedial courses, he can take graduate engineering courses which will keep him fully abreast of the developments in engineering science. He will also immediately have the prerequisite for taking the bio-engineering courses and will be able to obtain a rather complete background in a number of contemporary aspects of bio-engineering. This will also give him an advantage in choosing a thesis topic early, and developing it into a major scientific contribution.

ROLE OF ENGINEERING SCIENCE

Bio-engineering is a two-way street and in education has made considerable contribution to the development of engineering science. It does this by being a source of thesis problems. Many engineers who are not particularly interested in bio-engineering find it profitable to do their doctoral thesis work, or undergraduate and graduate projects, in the life-science field because of the severe test that the life sciences place on the application of engineering theory. Much of the problem of engineering education, with the increasing attention given to complex mathematical analysis, is to find interesting real systems of enough complexity to test modern theory. Thus, there exists clear utility for bio-engineering as a schooling ground for these engineering science principles.

In any case, engineering is encompassing more and more aspects of the descriptive sciences--it now plays an essential role in physics and biology and is beginning to play an important role in sociology and linguistics. A hopeful side of bio-engineering training is that with the further development of engineering and system science--especially in such fields as control, communication, and information--it looks as if all the sciences will become more unified and more interrelated. All sciences use input/output descriptions, study materials and energy conversion principles, and share common tools such as instrumentation and computers for model building. In this way, the unity of the descriptive sciences--physics, chemistry, biology, psychology--is becoming clearer as they share more and more the common structure of systems engineering science.

EXAMPLE OF A BIOENGINEERING COURSE

In order to give a better feeling for the bio-engineering training programs, this section, describes a single course in detail. "Biological Control Systems" is taught as an advanced graduate course. Prerequisites are a first graduate course in control systems and, as well, background in physiology, either the medical school physiology course or equivalent.

The course is divided into two parts: (1) a lecture series which covers developments in biological control with an emphasis on neurological control systems so that the student becomes familiar with the research results of the past 10 years in considerable depth; (2) a prepared laboratory, now stabilized at seven experimental laboratory sessions, and which is the most exciting part of the course. With more advanced students, each session can occupy two afternoons so that excellent results would be expected of the laboratory group. The students are arranged in small teams; particular care is taken to have one good biological experimentalist and one good electrical engineering student in each laboratory group of three or four students. It has been found that a good deal of the learning in this course takes place in the interaction within the laboratory groups--while doing experiments, while being briefed, while discussing their results, and especially while writing their laboratory report. It is thrilling to hear an engineering student explain to a biology student why the Bode plot gives so much detailed information concerning a particular dynamical system. Similarly, it is exciting to hear a biologist explaining to an engineer why the fact that poor results are obtained in the first run does not mean that the experiment has to be abandoned or that new equipment needs to be built, but rather that more practice and careful attention to the details of the experimental procedure and the condition of the subject might very well lead to the desired "better" results.

The seven laboratory sessions are chosen with a number of different interwoven aims in mind. It is desired to review some important research results in biocontrol theory. A number of different engineering analysis methods are stressed. Several different biological preparations are utilized so that the student can get the feeling for a broad spectrum of possible instances of a particular control principle. Lastly, a variety of experimental techniques involving special bio-engineering transducers, analog-digital on-line real-time computers, and experimental maneuvers, such as clamping and variable feedback, are introduced to the student.

The laboratory sessions are as follows:

1. Torque pulses are applied to the arm by the computer-controlled transducer. The resultant *impulse response* or weighting function is analyzed with a second-order differential equation as a model. This is done both by pencil and paper calculation and by the on-line digital computer. Subjects may change their dynamical characteristics by tensing wrist muscle tension, and these changes can be followed quantitatively.

2. *Sinusoidal analysis* of a crayfish nerve impulse system is performed. The stimulus is sinusoidal oscillation of light intensity and the response is average frequency of the nerve impulse train. This introduces the student to frequency domain analysis in the simplest way--without feedback.

3. Transients of light are used to stimulate the "open loop" pupil of the human eye. This highly *non-linear* system shows quite different results than in the first quasi-linear experiment. Thus the student is introduced to the complexities of non-linear analysis in a relatively straightforward input/output experiment without feedback on an involuntary neurological reflex response.

4. An experiment, utilizing either the pupil or the fusional vergence system, introduces the concept of *feedback*. By changing the feedback conditions electronically (environmental clamping), we can alter the stability of a system, make the system unstable, and drive it into oscillation. Here the principle of feedback is utilized to understand stability conditions and to make quantitative predictions concerning the frequencies of oscillation.

5. The hand-tracking system is not at all an involuntary neurological reflex, but a complicated voluntary movement. The human can look at repetitive characteristics of the input signal, make predictions, and alter his response characteristics. This *prediction operator,* an input adaptive mechanism, can be studied by comparing the response of a human subject to single sinusoids which can be predicted, and to multiple sinusoids superimposed, which give an irregular unpredictable input. The experiment defines an adaptive control system property generally present only in biological systems.

6. The eye movement tracking system demonstrates discontinuous or *intermittent* properties which can be approached using sample data engineering control theory. The eyeball has very low inertia, and most of the output dynamics are a result of neurological computations: in particular, the intermittency shows up well in these experiments. A further approach to the importance of feedback is obtained by extending these experiments to include variable feedback conditions as in item 4.

7. The pupillary system shows a good deal of a high-amplitude *noise.* The final laboratory experiment defines the frequency and distribution characteristics of pupil noise considered as a stochastic system, and ensemble characteristics of the noise during an ensemble of separate responses. This enables the students to utilize statistical communication theory, to understand the importance of noise in biological systems, and to study the experimental use of multiple inputs and multiple outputs to help define internal elements of this biological control system.

The *engineering topics* covered are time domain and frequency domain linear analysis, certain non-linear methods, such as describing function and phase plane analysis, the treatment of discontinuous system, statistical communication theory, input adaptive control systems, and pulse frequency coding. The *biological preparations* range through nerve fibers, involuntary human reflexes, such as the pupil response to light, and volitional behavioral responses, such as eye/hand tracking. The *experimental techniques* involve transducers, on-line computers and various clamping and multi-input/output approaches to these neurological systems as well as dissection of invertebrate nervous systems to obtain single-unit responses.

AIR TRANSPORTATION

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New York, N. Y.

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The problems of transportation in this country are legion; and it often seems the system is a mess. Given adequate money, manpower, research capability, and computer time, maybe some university group, some superagency, or some company adept in systems analysis could sort all the problems out and create a model transportation system--on paper. Then the fun would begin. As our society is organized, how would you motivate one element of transportation, or one group within that element, to agree that it was in the best interests of the system to make inevitable sacrifices? How would you convince individuals that the public good required personal dislocation? This is not to say that a coordinated transportation system is not a goal toward which to strive. It is to say, however, that these matters are best left to people who have a dispassionate interest in them and who are not intimately involved with trying to make one segment of the system as useful as possible.

I shall limit my remarks to aviation, and more specifically to airlines. We have more than enough control problems of our own to solve as we strive to make a maximum contribution to the economy and hence to our own growth.

THE AIRLINE INDUSTRY IN PERSPECTIVE

To put the airline industry into a bit of perspective, last year the U.S. airlines flew 150 million people 114 billion revenue passenger miles. By 1975, we estimate serving 300 million people, and world-wide passenger mileage is expected to pass 1 trillion by 1980. U.S. cargo ton mileage totaled 4 billion last year; it is expected to grow to 10 to 12 billion ton-miles by 1975.

In the past, even the most optimistic predictions in our business have turned out to be low. This could also be true with the above projections, particularly as an increasing proportion of the population has more money to spend, more leisure time in which to spend it, and a greater desire to expand social and cultural horizons.

However, there are potentially inhibiting factors to this growth.

The major one today -- and in the foreseeable future -- has a simple lable -- *congestion.* You have all probably experienced it--in the air, at the airports, and on the ground. We know from last summer's frustrations that the system creaks and groans like an antiquated pipe organ. By all predictions, the coming summer will, at best, be not better.

The difficulties are simple. As it is now utilized, there is frequently not enough airspace in certain areas for all the airplanes trying to use it at one time, and there is not enough runway concrete to meet the demands for it. The causes are more complex. If the airlines and general aviation had grown at a nice sedate pace, today's airways—airport system might be adequate. But they haven't. They've exploded like milkweed after the first autumn frost. Facilities have lagged far behind. Part of the trouble is money. The Federal Aviation Administration simply has been unable to get sufficient funds to make badly needed and technically feasible improvements in the present system.

NAVIGATION IMPROVEMENTS AND PROBLEMS

For example, all airline aircraft and many general aviation airplanes are equipped with radar transponders. When the ground controller asks a specific airplane to identify itself, the pilot merely presses a button and what had been just another blip on the ground radar scope becomes larger and brighter momentarily. This improves the control of traffic and adds a margin of safety. However, now the principle has been carried considerably further. Nearly half of airline airplanes have what are known as *alpha-numeric,* or *three-dimensional* transponders which display not only a brighter, bigger target on the scope, but also the name of the airline, the flight number, the airplane's altitude, and whether it is ascending or descending. However, the system, which must be cooperative, is out of phase; only two airports have ground radars with the capability of accepting this additional intelligence.

The situation with airport landing minimums, which have much to do with the efficiency of terminal area operations, is roughly the same. At most airports, if the ceiling is below 200 feet and the lateral visibility less than one-half mile (generally expressed as 2600 feet runway visual range), a jet has to orbit the airport waiting for better conditions or go elsewhere. Capability exists today to lower these minimums to 100 feet and 1200 feet runway visual range, through improved autopilots and use of radio rather than barometric altimeters in the airplanes and improved airport facilities, such as more accurate instrument landing systems and touchdown zone and centerline lighting. The airlines have been making the cockpit improvements and training their crews to fly the new minimums at a steady pace, but to date only 11 runways in the U.S. are equipped for the improved operation.

In this area, Europe is ahead of us. Fully automated all-weather landings have been routine at several airports for some time. Nevertheless, the airlines in the U.S. are having this capability built into the next generation of jets in the hope that the ground systems will have caught up, or, indeed, that superior ones will have been developed.

Airspace, per se, is not a scarce commodity. Airspace -- as today's airways system operates -- is. Currently a number of experiments aimed at expanding the volume of usable airspace are being undertaken or planned. For several months, American Airlines, for example, has had two Boeing 727's flying between New York and Chicago in scheduled service using an off-airways navigation system (developed by Butler National Corp.), called a vector analog computer (VAC). As the name suggests, the VAC allows the plane to fly a phantom track either to one side or the other of the regular VOR/DME airway, automatically computing and displaying pictorially the aircraft's position and then allowing the plane to fit automatically into the approach pattern at destination. Using airspace that would otherwise be empty allows us to save up to 15 minutes over this relatively short distance.

Another approach to better airspace management is through use of inertial navigation. American Airlines became the first airline certified to use inertial navigation in place of older, more conventional systems for overwater flights last summer. The Litton system we use operates completely independently of any ground facilities and makes fixes in microseconds that would take a human navigator several minutes to calculate. And any navigator will tell you it is more accurate. It is so accurate, in fact, that our freighters flying the 5000-mile leg between Japan and California have come within 200 yards of their target.

Recently, we have been conducting experiments using the inertial system as the basic means of navigation across the U.S. With it, the airplanes can, of course, fly the most direct route between two points, again using otherwise empty airspace and saving time.

These two navigation systems will be a key part of another experiment American is about to undertake. Next month we will begin tests and evaluations of the Breguet-McDonnell Douglas short-takeoff-and-landing (STOL) airplane. We particularly want to find out whether an airplane of this type could be used to provide a viable service, not only between present city center airports, but also between airports too small and not adequately equipped to handle today's conventional airplanes. Again, the goal is to try to expand the usefulness of the airspace and the utilization of the concrete, at the same time giving customers a superior service over short routes. The STOL being used for these current experiments is not big enough for economic airline use, nor is any STOL aircraft now in existence. However, if the concept proves itself we hope that manufacturers will become interested in making an airline STOL plane. Our development engineers anticipate that planes of this type could be in use along about 1972.

Experimentation with new navigation systems does not end with the Butler VAC or Litton inertial system. Decca has a system similar to the VAC, though considerably more sophisticated, that also will be included as part of our STOL tests. United is testing a Hughes-Jeppesen off-airways navigation system, also on the New York-Chicago route. The airlines are sharing results of these evaluations, in the interest of developing the most useful possible system.

Beyond current hardware developments and tests, our scientists and engineers are engaged in a great deal of bluesky thinking about the whole subject of airways and airport traffic-control systems. The field is, to say the least, wide open for new concepts. There is nothing sacrosanct about today's radar-based system.

MORE CONCRETE NEEDED

Eliminating congestion on the ground at the airports simply requires more concrete. The problems here are financial, political, and social. It costs more than a half million dollars to build a major new airport from scratch. Then comes the question of where to put it. Travelers want airports as close to the heart of the city as possible. Many of our cities have no reservoir of convenient property. People who live near suggested areas don't want airports in their back yards. The classic example of this is the much-debated search for a site for a fourth jetport for New York, which now seems to have been going on almost since the Wright Brothers. In the meantime, New York, along with Washington and Chicago, is about to be restricted in the volume of service the airlines can provide the public. And the airlines are about to be subjected to a condition which will artificially stunt their growth.

Unless some genius can figure out a way for airplanes to leave the ground without runways, for passengers to get on the airplanes without passing through terminals, for people to get to the airport without automobiles or other transit, it appears the only answer is more runways, more terminals, more parking facilities, and more access capability. It would be nice to be able to report that major progress is being made in solving the ground congestion problem through high-speed transit. Cleveland recently opened an airport-to-downtown rapid transit service. However, elsewhere there seems to be more of the same old footdragging. A hardy band of apartment dwellers in Queens is blocking the Metropolitan Transportation Authority's plans to provide a rail link between Kennedy and Manhattan. In San Francisco, work on the Bay Area Rapid Transit has come to a halt because of lack of funds. Last November voters turned down a proposed rapid transit system in Los Angeles. The outlook for better methods for moving large groups of people in metropolitan areas is not bright.

REDUCING SMOKE AND NOISE

Airlines make a great effort to be good citizens of the cities they serve. Currently they are working hard to minimize airplane contribution to air and noise pollution.

Airplane smoke is a negligible factor in pollution. However, the aim is to eliminate it as a factor altogether. Currently, several airlines are testing redesigned, smokeless engines on 727's. Engines under development are being designed to be smokeless at the outset.

Airplane engines will continue to make noise; the goal is to reduce the noise to the point where it does not disturb airport neighbors. Airlines spent $200 million on sound-suppression devices for the first-generation jets and accepted a substantial economic penalty in decreased efficiency of the engines. Recently, the technical attack has turned toward making the working parts of the engine quieter through use of sound suppression materials within the engine itself. For example, American elected to take a four-month delay in delivery of its stretched 727's so that the best soundproofing materials and techniques then available could be incorporated in the engine's design. The aim was for it to be no noisier than the lighter earlier version of the 727, and this goal was met. However, it did not come cheaply. The program added $68,000 to the price of each airplane, or nearly $3.5 million for the fleet of 51 which we shall shortly be operating.

Further progress is being made in the engines for the new, wide-bodied jets. In fact, we have added a maximum-noise-guarantee clause to the standard ones involving performance in our contract with the manufacturer. For the DC-10, which will be powered by General Electric engines, American has reserved 3500 pounds in powerplant design weight for provision of noise-control features, representing a sacrifice of 17 passengers per airplane. Total additional purchase costs involved will be some $200,000 an airplane, and we have ordered 25 of these big planes, with an option for 25 more. Expectation is that the DC-10 will be considerably quieter on takeoff and approach than the intercontinental 707's and somewhat quieter than the stretched 727's.

With airline support, last session Congress amended the Federal Aviation Act to require the FAA to specify maximum noise levels that an airplane can create as part of the certification requirements. Industry groups continue their research on defining the sources of noise. They are also searching for a formula which can be used to set standards for compatible land use near airports. In the technical area, NASA recently awarded contracts to Pratt & Whitney and General Electric to design and test experimental quiet engines.

THE JUMBO JETS AND THEIR RAMIFICATIONS

A whole new generation of jets, with a whole new assortment of problems, is upon us. These are the jumbos. Leading the parade will be the nearly 400-passenger (Figure 1), long-range Boeing 747 which Pan American hopes to put into international service by year's end. The 747 will be flying domestic routes early next year. Coming along in late 1971 and 1972 will be the 250-passenger medium-range jumbo tri-jets, the DC-10 and Lockheed 1011.

The size of these airplanes promises considerable operating economies. They will help relieve the congestion problem by transporting more people on a single flight. Their cavernous interiors should appeal to passengers, since they are so big that the long, thin-tube effect of today's jets is gone.

These airplanes will incorporate all we have learned in the decade of jet operation about instrumentation and systems and should not have the reliability problems that typified the early jet days. But all the electronic wizardry in the world cannot tell us how to handle 350 people at once with supermarket efficiency and drawing-room graciousness. Airlines have always prided themselves on the personal service they give customers. As the volume of business expands, it becomes increasingly difficult to retain the personal touch and, at the same time, provide expeditious service, and the 747 will magnify this problem considerably. We do not want to compromise either objective, so our planning becomes an exercise in trying to provide a delicate balance between the two.

Figure 1 - In the era of the Jumbo Jet, the matter of unloading 400 or more people from the aircraft presents a problem of great magnitude to airline logistics personnel.

Terminals, tickets, and bags are some of the major problems of the jumbo-jet age. We are trying various approaches toward solving them in our search to mate the supermarket with the drawing room.

Planning efficient, yet pleasant, jumbo-jet terminals, and ones that we can afford to pay for, is a complex business. However, we do have one thing going for us now that we did not have when we introduced the first jets, and that is the computer. We have computers figuring out our needs through 1978 for gate space, schedules, food, ticketing, passenger flow, and even the number of visitors to expect at any airport at any time on any day.

This is invaluable information. Some of the early jet terminals were practically designed on the back of an envelope, and worked about as well as one would expect. Terminals are a big headache, but at least the ailment can be diagnosed. We know that given a particular pattern of service there will be X number of flights scheduled to leave a particular city during the peak hour. We also know that to operate these flights we will need Y number of gates. But we also know that one of these gates will be used only during the peak hour. Terminal space is an expensive commodity. So do you reschedule or not operate a flight and turn the business over to a competitor? Or do you go ahead and build that extra gate? Or do you find some other way to get those passengers on that airplane? At American we have a group that is spending almost all its time trying to answer these questions. For example, they are looking at the possibility of handling the peak-hour overflow with people pods, similar to those currently in use at Dulles Airport outside Washington.

Then there is the matter of getting 400 people off and on the airplane. It is apparent that more than one loading bridge is necessary. Do you load everybody through the front doors? Or do you use the front door and have a swing-out device through which people board through the overwing entrance? Or is there some better way to do it?

Ticketing is another problem. We are working on an automated computer device which will be as simple to operate as a cigarette machine. A passenger will insert a credit card and give the computer relevant flight information. The machine will instantaneously check flight availability, check validity of the credit card, compute the fare, and issue the ticket.

Baggage is the biggest customer-service problem we have today, and the thought of 500 bags (Figure 2) and their owners arriving in one spot at the same time is staggering. Baggage handling must be automated. The industry is working with Recognition Equipment, Inc., on one possible system that could deliver any suitcase from any point in a sprawling terminal complex to any one of hundreds of other places in a maximum of 180 seconds.

The system uses small luggage cars driven by a linear induction motor at a basic rate of about 20 miles an hour. The cars, each carrying one passenger's luggage, can go up walls, down slopes, or around corners, carrying baggage to planes, garages, check-in counters, between airlines, or a variety of other locations.

When he checked his luggage, a passenger would receive a coded baggage-ticket stub. The stub would be inserted into a reading device and the coding would program the car to go to the

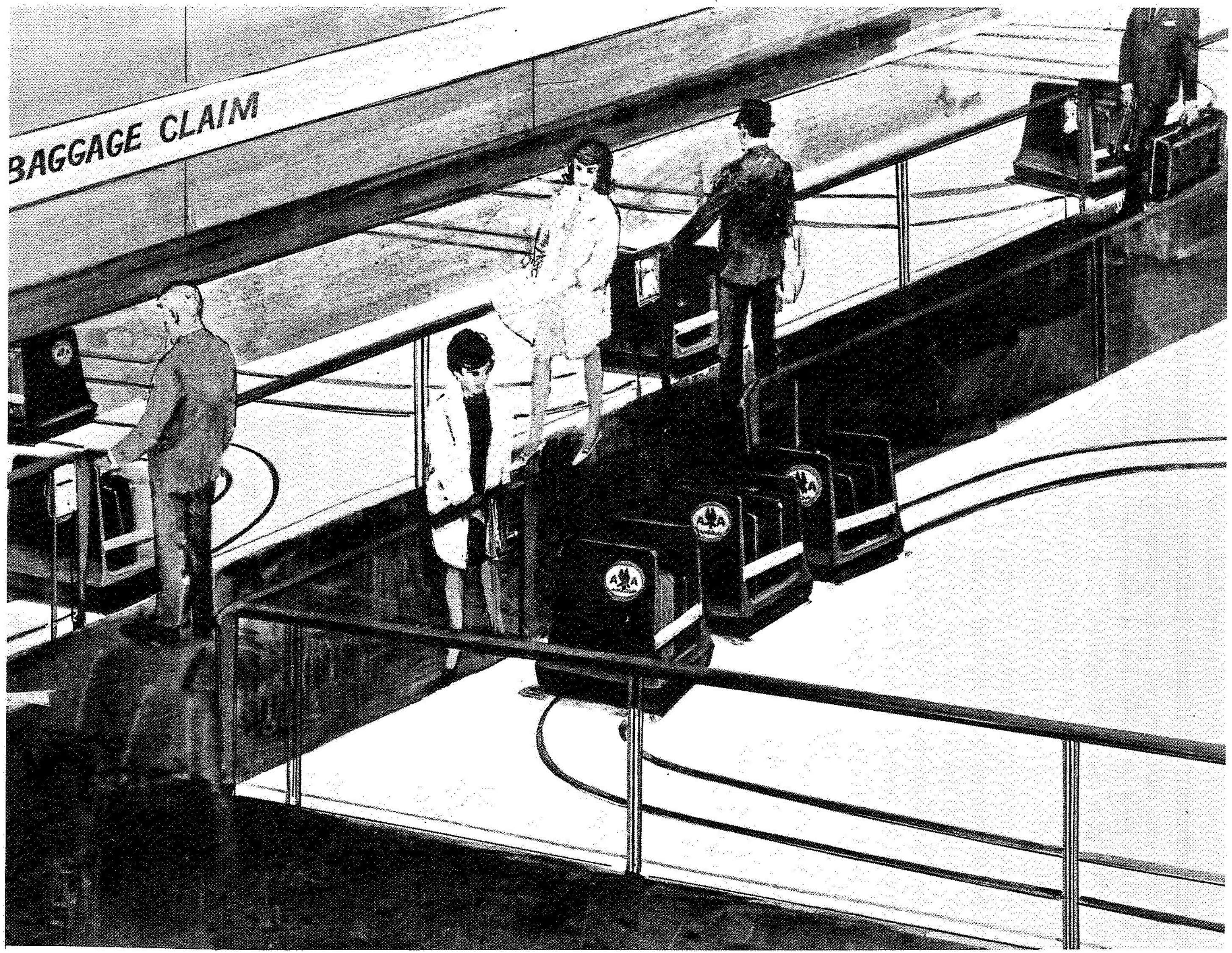

Figure 2 - Baggage is the biggest customer service problem the airlines have today. Extensive planning on the logistics of handling 500 and more pieces of luggage efficiently and quickly is underway as aviation faces the "Jumbo-Jet" era.

correct airplane or other location. When a passenger arrived at his destination, he would go to one of various locations and place another stub in the reading device. The coding of the stub would direct a luggage car with his suitcase in it to him. This system, or something akin to it, probably will become a key feature of jumbo-jet airports.

APPLICATION OF COMPUTERS

Controls, computers and automation are also very much an integral part of our maintenance operation and becoming more so all the time. The stress during recent years has been more and more toward prediction of potential problems and diagnosis of them before they cause a breakdown. Automatic testing and monitoring equipment and computer analysis of problems characterize today's maintenance operation. This trend will become accentuated in the future.

Let me review one example. American is pioneering in installation of an airborne computer monitoring and recording system, not surprisingly dubbed Astrolog. An engine performance computer takes readings during six phases of any flights, recording each time seven key indicators of engine health. Every night a ground computer analyzes each engine's performance that day and determines whether any faults are developing. In case there are problems, the computer will identify the most likely faults and estimate the urgency for corrective action in terms of the likelihood of inflight engine shutdowns, flight delays, and cancellations. Reports go immediately to maintenance and engineering specialists so that corrective action can be taken.

Astrolog has further talents. It also monitors flight performance. The black boxes monitor all aspects of a flight from the time the trip leaves the gate until it docks at destination. The system measures three dozen flight characteristics, such as takeoff speed and deck angle; flap settings; climb, cruise, descent and landing speeds; and bank angles and descent rates. Tapes are removed from the airplane at the end of the flying day and fed into a computer which reads all the data and prints out exceptions to the programmed limits. Astrolog is not in any way designed as a disciplinary tool; in fact, our pilot's union worked with us on its development. It is designed, rather, to give management the opportunity to evaluate scientifically the effectiveness of training programs, flying procedures, and policies it has developed and to correct any deficiencies that become evident.

Airborne computer monitoring is actually in its infancy in airline use. Someday, it is hoped, systems techniques now used to collect engine and performance data can be extended to monitor airplane systems and instruments so that maintenance people will have a complete picture of an airplane's health every night of the year.

THE AIRFREIGHT BUSINESS

So far I have touched upon work that my colleagues are engaged in and problems and opportunities they have. We in the freight business have more than enough of our own challenges. Our business is changing at lightning speed. I am continually telling my associates that not a single thing we are doing now will be done the same way five years from now. When I describe the airfreight picture in the U.S., I realize that I am describing a business that will be changed by the end of this year, substantially changed by the end of next year, and hardly recognizable within five years.

Techniques presently used (Figure 3) will be obsolete because of greater volumes, containerization, new tools, changing customer demands, economics, new aircraft, labor contracts, and probably a long list of other things that I haven't thought of.

Such rapid change requires an airline to examine continually the present status of airfreight, and forces us to make a constant effort to forecast where it is headed. This constant examination extends to airplanes, loading equipment, mechanization, automation, sales techniques, traffic congestion, the rate structure, paperwork and airfreight terminals.

We anticipate that airfreight will grow 15 to 20 percent a year for several years, or a 100 percent increase in four to five years. To handle this expansion, 18 scheduled airlines in the U.S. plan to spend $210 million from 1968 to 1971 on cargo facilities, and almost as much between 1972 and 1975.

During these years, I think that the only thing we can count on remaining the same is that trucks will still deliver freight to the dock of an airfreight terminal. The truck is an integral part of airfreight operations because an airplane can deliver goods only at airports. The truck is the link between the customer and the airport.

However, the truck faces congestion that is multiplying at an alarming rate. During the middle of the day, when most truck deliveries are made, it can take a truck 45 minutes to get across the narrow island of Manhattan. Consider then the truck in the developing megalopolitan areas between Boston and Washington, San Francisco and San Diego.

An obvious solution to this traffic jam is to make deliveries at night, when fewer vehicles are on the streets. Why not? There are numerous reasons, including labor contracts and the wishes of customers, but we may have to come to this as San-San and Bos-Wash become realities.

Another controlling fact of life for airfreight is that factories produce goods during the day and are ready to ship these goods at the end of the regular working day. So trucks are loaded then and head for the airport to turn the freight over to the airlines. This builds up to a peak in airfreight operations inside the freight terminal at about 10 p.m. We haven't had much luck in changing this pattern; customers want their goods moved at night so that delivery can be made in another city early the following morning. The situation has one definite virtue: airfreight operations add little to congestion in the air.

On the ground, the problem of freight terminals is with us always. A ruling fact is that there is no such thing as a master plan for freight terminals. Each is affected by many factors--among them, forecasts of traffic, availability of land, the kind of airplanes that will be flown.

The new freight terminal we are building at Kennedy Airport serves as an example. Kennedy is an extremely important link in our freight network; 15 percent of all of American's freight is handled in our current facility there, and it is the gateway for our ties with the trans-Atlantic airlines.

In planning future facilities at Kennedy, or any other airport, we must assess the estimated tonnage it will handle, the revenue it will generate, and its potential profitability. Our present

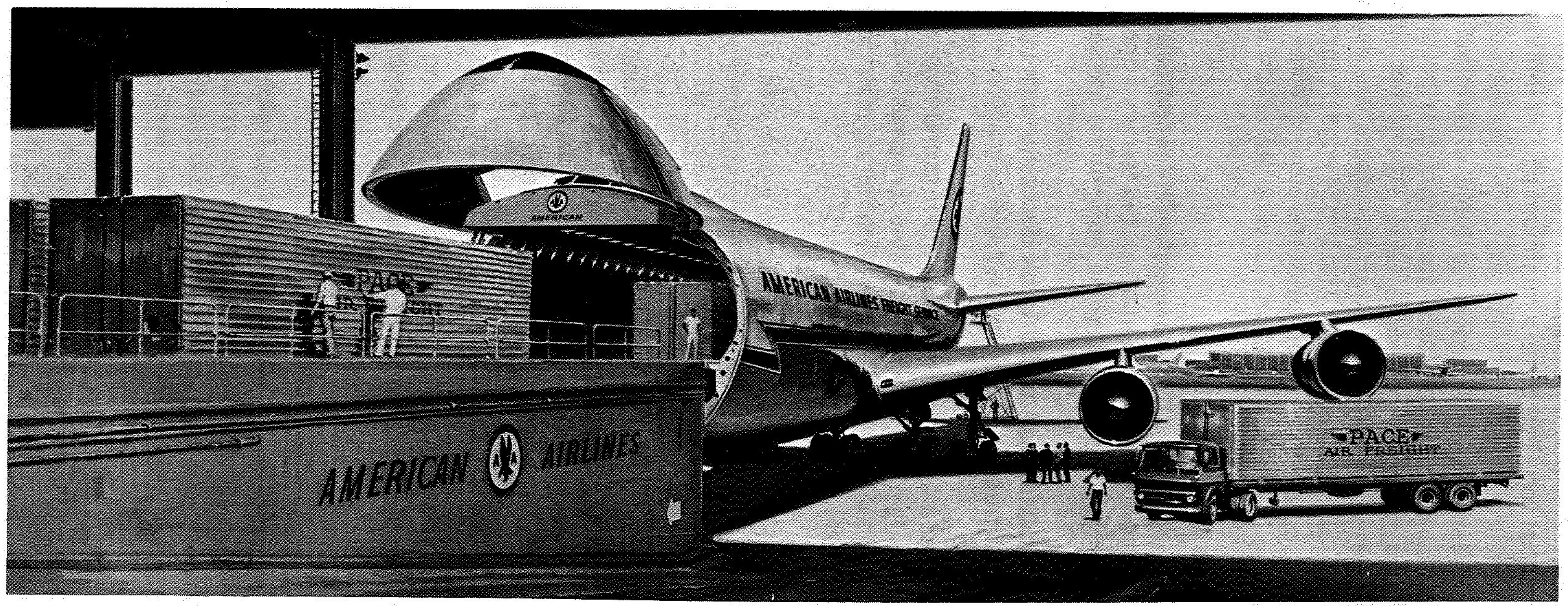

Figure 3 - Present airfreight techniques will be obsolete in the "Jumbo-Jet" age in view of greater volumes of freight, containerization, new tools, changing customer demands, economics, new aircraft, and labor contracts.

Kennedy freight terminal handled about 200 million pounds of freight last year. Our corporate planning department estimates the potential for 1975 to be a minimum of 700 million pounds.

American already had land available on the airport to build a terminal to handle this volume. This fortunate situation took care of one problem--space--which is becoming critical at some airports. Some of the space that *is* available has serious flaws. At another airport where we needed a new freight terminal, the airport authorities assured us that space was available. A quick look showed that the land area was large enough, but that it was at one edge of the airport and was not connected in any way to the runways, taxiways, or ramps of the airport. When we pointed this out to the airport managers, they told us it was our problem – a problem which ended up adding $360,000 to the cost of the facility.

The Kennedy terminal of American, which will be longer than three football fields, will have five airplane positions, with at least three of these activated when the terminal opens in mid-1970. These will be capable of handling any size airplane that will come along in the foreseeable future.

On the opposite side from the airplanes will be 69 truck docks for pick-up and delivery. I assume that I am correct in predicting that trucks will still be used five years from now.

Next comes the problem of cost. I started to list this as the first and most critical problem, since I am not an expert at signing authorization papers for freight terminals that cost almost $12 million. It seems a lot of money for a building that, in theory, is simply a place to transfer freight across a stretch of flooring from trucks to airplanes.

I didn't list cost first, however, because the investment in a terminal is justified or not justified by many factors, such as its location, the revenue it will generate, the amount of freight it will handle, and the cost of its operation.

A number of aviation officials have discussed the possibility of building freight terminals away from airports, in the industrial sections of cities where land costs less, where more efficient terminals could be built, and where ground traffic would be lighter. Trucks would load freight containers and carry them to plane-side on the airport where they would be loaded and then the plane would depart.

American now operates from an off-airport freight terminal in Cleveland. Though it works reasonably well, actually it was forced upon us. We had no choice; there simply was not enough land available on these airports to build facilities that could handle present volumes and provide capability for future expansion.

As things stand now, it is desirable to be on the airport. Jet-freighters are loaded and unloaded there. Freight-forwarders, who supply a substantial part of our volume, are there. So are other airlines, and interline shipment of freight is an important part of our business. The same may not hold true five years from now. The off-airport freight terminal does have possibilities of reducing costs, and the idea deserves a lot of study.

A related proposal is to build entire airfreight centers away from airports. This would include facilities for airlines, forwarders, customs, and everything else needed to accept, process, and distribute airfreight. The 1970's may bring something of this nature. I would be the last to reject it out of hand. However, it would take a lot of money to build such centers. It would require a lot of people agreeing to leave the airport and a multitude of agreements about who would use what.

Until one or more of these possibilities seems practical, we plan, without much choice at present, to build and expand freight terminals *on* airports where possible.

GROUND-HANDLING FACILITIES

The ground-handling facilities inside and around freight terminals represent one of the airlines' major headaches. Everyone agrees that the real breakthrough we need is in development of efficient ground--handling techniques and equipment. This discussion automatically leads to the subject of mechanization and automation of terminals.

In a recent survey of 14 domestic airlines, ten indicated they intend to automate their air-cargo facilities to some extent by the early 1970's. They agree--and I agree--that we must introduce more automation into our terminals if we ever expect them to be efficient. But there are all kinds of automation, and so far the experience of airlines with freight-terminal automation hasn't been very happy.

These freight-terminal handling systems, and I include the new ones, have not proved to be the panacea that many had hoped. Not one system has reduced costs. To complicate matters further, some of them are geared to handle only small packages. It is a harsh fact of life that small packages hardly pay their way, and frequently don't pay their way, so some of these systems were actually designed to handle traffic that is marginal at best.

Although I insist that we must mechanize and automate our terminals to a degree unknown today, at American we have adopted a somewhat skeptical attitude. Before we buy anything, it must be proved that it works, that it pays for itself, and that it increases efficiency rather than simply complicating the job.

We expect to mechanize the new Kennedy terminal to a greater degree than any of our present terminals. Even at this date, however, we are leaving ourselves options on the freight handling system within the terminal. We look forward with some confidence to installing a system of air pads on the terminal floor to move loaded igloos, containers holding up to 10,000 pounds each. An igloo can be moved with little more than the push of a finger. These air pads, or air cushions, have been tested in our San Francisco and Los Angeles freight facilities. Here in Boston, our terminal now has a section of the production line equipped with air pads. The outlook for this system is bright and we are continuing to develop it.

We will continue to use our proven Astro-loaders, or something akin to them, to lift the freight into the jets. One Astro-loader, basically a system of powered rollers and lifts, can unload 90,000 pounds of freight from a 707 jetfreighter in 20 minutes, then load up the airplane again in the same length of time. We expect to automate the interior of our present jetfreighters and any we may buy in the future, and will extend this automation to the bellies of the 747's and DC-10's.

SOME QUESTIONS FOR CONTROL TECHNOLOGY

I hope this brief outline of some of the things that are going on in the world of airfreight has convinced you that everything is indeed subject to change. We are actively seeking new ideas and new ways to do business. To give you something more to think about, I would like to toss out some questions:

- *Why have freight terminals at all? Wouldn't it be possible to pull a freighter into a parking lot, then have trucks place pre-loaded containers directly into the airplane?*

* * * * *

- *Are trucks really necessary? Is our reliance on them a sign of our own failure to figure out something better?*

* * * * *

- *Can a freight-delivery system built around helicopter cranes be developed?*

* * * * *

- *How can we speed transfer of freight between airlines? Now it sometimes takes more time to move freight a mile and a half at Kennedy than it did for the shipment to arrive from Chicago.*

* * * * *

- *Can freight be transferred through a giant pneumatic tube? Or, at least, isn't there some way the operation can be taken underground?*

* * * * *

- *Can freight be moved on a monorail? Or on a system powered by linear induction motors?*

* * * * *

Airfreight is a wide open field for almost any kind of questions and answers because there is so little past experience to provide guidelines. The whole field has turned over in the last five years, since the jets arrived, and we expect it to do the same in the next five years.

The ultimate question, of course, is: will airfreight be profitable?

Airline rates are controlled by the Civil Aeronautics Board. Today's rate structure is largely a carryover from the days of piston airplanes. The airplanes have hampered themselves by some of their competitive practices. Airlines have not always emphasized the customer's needs, rather than their own.

The results so far have been mixed, with airlines generally showing losses or miniscule profits on the operation of all-cargo airplanes, and showing some profit on the freight carried in the bellies of combination airplanes.

So, the airline business generally, and the freight business particularly is in a rapidly changing, evolutionary environment. We have many problems and few guidelines. We have great hope for our future with full knowledge that our horizons are not all clear.

URBAN STUDIES: AN OPPORTUNITY FOR SYSTEMS ENGINEERING

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* * * * *

This gathering of leaders of control theory in the United States could mark a major rededication of our profession. Many of us can agree, I think, that the rate of advance in control has slowed recently and that an influx of socially relevant problems to be solved could give new life to the field.

The *large-scale system* represents a class of problems with many unsolved theoretical questions whose answers could have great social value. Large-scale systems occur in economics and bio-engineering as well as in the technology of our man-made world. The city as a system represents many challenges, as do distribution networks for electric power and transportation.

SYSTEMS APPROACH

I argued in the April, 1968, issues of the *Proceedings of the IEEE* that a systems approach to the national transportation problem is an important concern for today if such a system is to be ready for the turn of the century. One early outcome of such a national transportation system study, if I may speculate, would probably be a differentiation of mode of travel as a function of distance of travel. One such suggested division is shown in Table 1. There appears little rationale for the present indiscriminant jumbling of transportation modes which are independent of their performance characteristics. I have flown regularly scheduled airlines from Providence to Boston, a distance of 45 miles, and Providence to Hartford, not much further, and I have driven my automobile several times from coast to coast. Furthermore, I would wager that my experience, as irrational as it appears, is not untypical. Present plans for using generally high cost airborne transport systems, such as helicopters and V/STOL, for short-stage-length, high-density routes along the Boswash corridor seem to be quite at variance with reason and prudence.

TABLE 1. EFFECT OF TRAVEL DISTANCE AND MODE ON TRIP TIME

Travel Distance (miles)	Mode of Travel	Average Speed (mph)	Elapsed Time (hours)
50 to 150	Personal Vehicle	50	4
75 to 750	HSGT	250	4
500 to 2500	Jet Plane	500	4
2000 to 6000	SST	1500	4

One cannot study the transportation needs for an integrated metropolitan region from this global point of view, however. For this problem one must view the urban regional transportation network as imbedded in a matrix of many other systems which together make up the city.

THE CITY AS A SYSTEM

It becomes clear, as one thinks about it, that a model cannot be constructed without knowing the questions which the model is designed to investigate. A model can be isomorphic with reality in only a few selected ways. Thus one must choose those attributes or parameters of the city which are to appear explicitly. Here are several possible approaches:

1. Suppose the city model is to be used in a regional or national distribution or economic system study. Then the city can be taken as a dimensionless node in a larger net. Laws of conservation of people, money, energy, and material could be applied perhaps to write laws of motion. Only aggregate flows can be considered and no information about reactions internal to the node can be obtained. Time will be the independent variable for the analysis and probabilistic methods may be employed.

2. Suppose the model is to be used for determining the optimum location of specific processes and/or networks within a metropolitan region at a given point in time. Now, the model must preserve distance as an isomorphism; that is, the model must be a geographic one in some sense.

3. If the model is to predict growth and changes in land use within the region, the matter becomes more complex. Economic processes must be superimposed on the spatial (geographic) model. Neither the economist nor the architect is likely to feel comfortable in such a situation. Let us take this case under advisement.

GEOGRAPHIC BASE

If land use is to be one of those specific parameters to be investigated, the model must have a geographic base. There are several good reasons for adopting existing political subdivisions within the region as the cells of the model:

- Economic and demographic data are available in these terms;
- Political regulations, such as zoning and local taxation, will follow these patterns;
- In communicating his results to the outside world, the model builder will find his task eased by using this familiar breakdown.

Given the cells within the region, the model builder will next wish to establish the indicators of pertinent activities and the values of the various coupling coefficients between the cells.

In a model for greater Detroit, the six most populous counties located in Wayne County, appear to be a reasonable approximation of the major components of the city, although it should be noted that Detroit's region of influence extends well beyond this. Having established the geographic cells for a particular level of the model, one will wish to model the activities within a cell and its cross coupling to other cells. We repeat that such a structure cannot be erected without implying the questions to which the model is relevant. But rather than making a chicken-or-egg argument about questions vs. activities, I will list five possible activities:

1. Industry and commerce;
2. Utilities and service;
3. Transportation and communication;
4. Banking and finance; and
5. Population and land use.

Activity models can be constructed for each geographical unit and cross-coupling coefficients established to each of the other geographic units. It is possible to construct still more complex geographic or activity models. It is also possible to select certain segments of the model for detailed analysis while other segments are maintained at a lesser degree of sophistication.

The specific models of the city used as an illustration above probably won't work in practice. For one thing, they are not entirely clear on the distinction between the "process model" of the input/output model, with money as an indicator and time as the independent variable, and a model that uses space or distance as the independent variable. In effect, we must decide if we are playing economist or architect/city planner before beginning to model.

I suspect that a model using various economic indicators and divided into ever more fine geographic cells may be more satisfactory than attempting to measure "happiness" and "humanity."

A SYSTEMS APPROACH TO URBAN TRANSPORTATION

A transportation network is similar to other distribution systems and many analytical techniques developed for telephone systems, for example, are useful for urban transportation systems.* A transportation network must include three basic fundamental operations. Only one of these three is interesting, simple to design and construct, and provides the opportunity to earn a decent rate of return on investment. This may be why most proposed systems are doomed to be at best one-third successful and why people insist on using the "non-system" mode.

The three elements of a transportation network are collection, line haul, and distribution. Almost no one lives in a bus depot or railway station and hardly anyone making an airline journey has as their destination the airport terminal itself. Thus, it is incorrect to think of a line-haul system or even groups of line-haul systems as a "transportation system." A line-haul system moves you from terminal to terminal and then the devil take you. Most mass transit systems for urban commuters are aimed only at the line-haul segment constituting the journey to work. This is a major reason for the rise of the automobile and the fall of mass-transit commuter service. The automobile is a "non-system" and is supremely inefficient in the line-haul phase of a journey. It is superior, however, to any conceivable alternative for the collection and distribution phases in the conventional city.

By definition, a system study concentrates on the overall characteristics of a transportation network such as cost effectiveness, speed, cost, and trade-offs among modes. Only if a parameter sensitivity study reveals that a particular aspect of the system performance depends critically upon one or another technical detail should the systems engineer pursue this parameter in detail. For example, the question of guide-ways and the suspension of various vehicles is certainly important. An air-cushion vehicle differs from a monorail device, which differs, in turn, from conventional suspension on rubber tires or steel wheels on steel rails. Yet, to a systems engineer these are trivial details within the single class of fixed-right-of-way vehicles.

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* W. Prager: "On the Design of Communication and Transportation Networks," in *Theory of Traffic Flow,* R. Herman, ed., D. Van Nostrand, Princeton, 1961, pp. 97-104.

COST EFFECTIVENESS ANALYSIS OF COMMUTER TRANSPORTATION

It is perhaps not surprising that one of the most penetrating cost effectiveness analyses of metropolitan transportation systems comes not from a civil engineering firm nor from a city transportation authority, but from a systems "think tank." RAND can take the longer view of the systems engineer.

> *Perhaps no aspect of urban transportation planning has been talked about so often but examined so poorly as the cost of providing comparable urban transport services by different kinds of technologies.* *

In general, the passenger convenience of mass-transit systems will never be comparable with the private auto. A possible exception is the special luxury bus service to and from the commuters' doorstep now under subsidized test in one or two localities such as Flint, Michigan and Urbana, Illinois. Furthermore, a fairly simple analysis shows that mass-transit schemes do not promise any significant speed or time advantage to the average commuter. Thus, cost must be the determining factor for popular acceptance of mass transportation.

The Meyer-Kein-Wohl (M.K.W.) studies of Chicago commuters show that 90 percent of mass-transit trips are less than 10 miles long and consume less than one hour (rail trips are longer, the 90th percentile being at 22 miles and 1 hour and 15 minutes.) Suppose 15 minutes are consumed in collection and distribution. Then doubling the speed of mass transit modes will reduce the 90th percentile trip to 37 minutes by bus and 45 minutes by rail. Since almost all transit trips are shorter, doubling the speed of the line-haul segment will offer a time advantage of less than 30 minutes to the average rider. We can see that, with speed and convenience ruled out, the only argument remaining for mass transit is cost.

A cost analysis of competing transportation methods is not difficult in principle. In following through a complete analysis, such as that performed by M.K.W., one is impressed by the difficulty of obtaining realistic values for certain critical parameters. In addition there are a number of performance assumptions to be made. Nevertheless, M.K.W. have completed this analysis for various trip lengths and densities of residential population.

I have extracted results for a ten-mile one-way trip on the line-haul segment for various modes from M.K.W. data. The results are shown in Figure 1. The cost of rail journeys does not depend upon residential population densities while auto-trip costs are extremely sensitive to this factor. This is caused by the high cost of urban freeway construction. For example, the Lodge-Ford Freeway in downtown Detroit had capital costs of over $9 million per mile more than 10 years ago. It has a peak capacity of 2500 persons per lane per hour whereas a lane devoted to the sole use of express busses can carry from 25,000 to 50,000 passengers per hour. Thus the high cost of the right-of-way directly affects the cost of auto travel. These costs are for only the line-haul portion of the commuter trip. The mass-transit option must build a big lead here since it will suffer losses in the other two segments of the total trip.

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* J.R. Meyer, J.F. Kein, and M. Wohl: *The Urban Transportation Problem,* Harvard University Press, Cambridge, 1965.

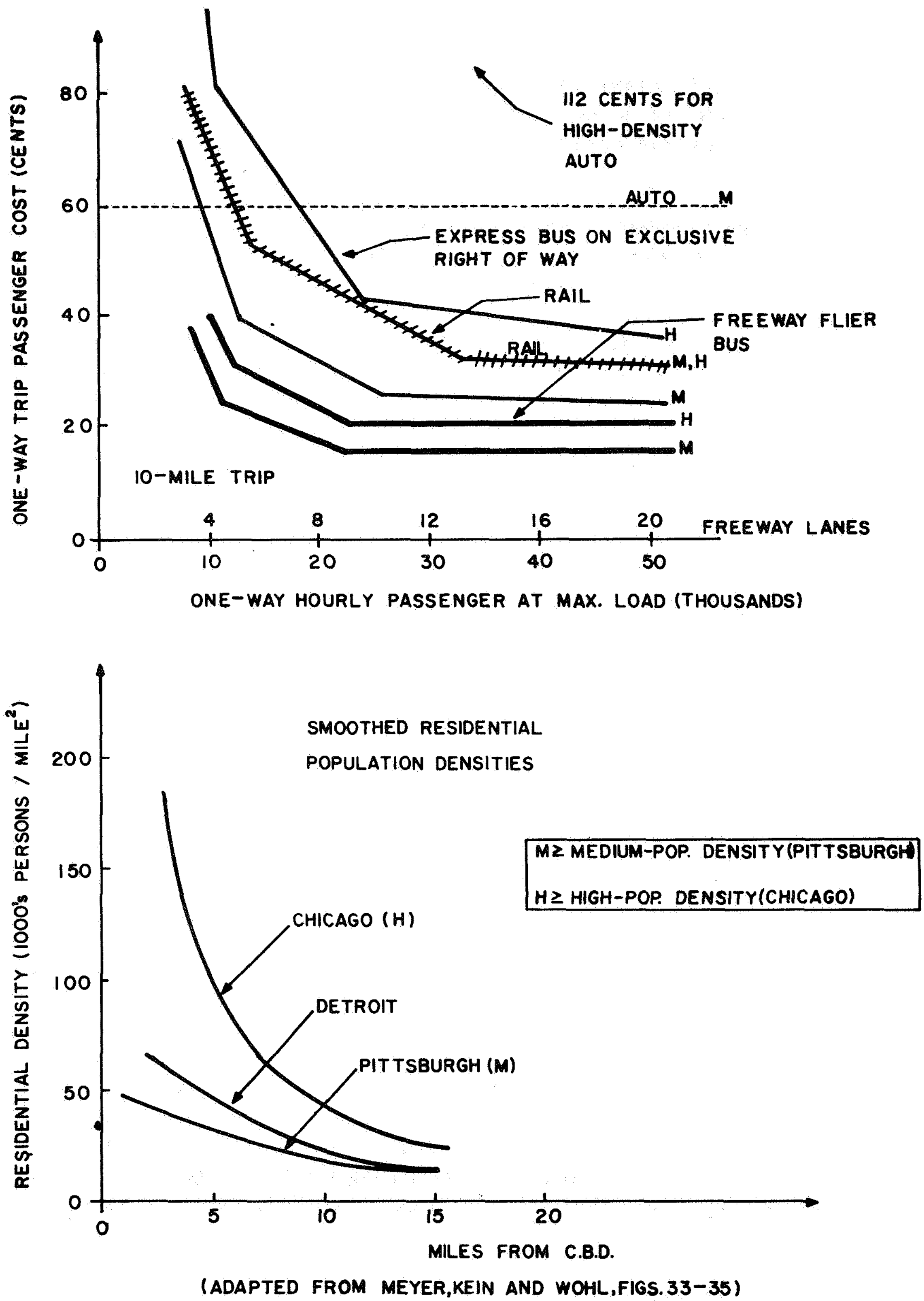

Figure 1 — Cost Analysis of Competing Transportation Modes

Let us now determine if we can estimate the cost in time and dollars for a typical commuter using rapid transit or his own automobile. The analysis and data in Table 2 are abstracted from M.K.W., but I must bear the responsibility of picking "typical" data.

The question to be answered by the auto commuter is the following. Are the added convenience, privacy, and time-saving of 40 minutes per day worth a dollar?

It is clear from the M.K.W. analysis why rail rapid transit continues to lose favor. Rail service on the line-haul segment combined with various collection and distribution modes is never more economical than bus and under certain circumstances sacrifices up to half the cost differential between rapid transit and auto commuting. Thus, the remaining advantage of rail over bus is speed and, under median circumstances, this difference cannot be significant. One wonders if the designers of the BART rail system in San Francisco now under construction are aware of this analysis. It may be, of course, that the special features of a commuter trip from Oakland across the bay to San Francisco provide a special opportunity for rail rapid transit. It would appear clear, however, that BART-like systems will not come into wide use generally.

TABLE 2. COMMUTER COST/TIME ANALYSIS*

	Cost per day (round trip)	Time per day (round trip)
Bus or Rail		
Collection	$0.15	20 minutes
Line-haul	.60	90
Distribution	.15	15
Total	$0.90	125 minutes
Auto		
Collection	$0.10	10 minutes
Line-haul	1.50	60
Distribution	.25	15
Total	$1.85	85 minutes

*Extracted from M.K.W.

It is even more difficult to justify the construction of permanent, exclusive rights of way for express busses. One occasionally hears an argument to rip out an existing commuter railroad and to devote the right of way exclusively to express busses. Such arguments ignore the cost of acquiring the rights-of-way from the railroad, the cost of replacing the rails with a smooth surface and the cost of providing new entrance and exit ramps from the right-of-way to the city streets.

This rough summary of an in-depth analysis is not intended to be conclusive. Rather, it indicates that systems analyses of pressing urban transportation problems are beginning to go forward.

THE FUTURE OF THE CITY AND THE CITY OF THE FUTURE

> *Irving Kristol says, "Critical history is for the wise social theorist what critical self-examination is for the wise individual: a severe exercise in demystification. No man who has not revised his opinions of the past is to be fully trusted as a guide to our opinions about the present and future."**

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Of course, the converse is not necessarily true. Merely to change one's opinions is not to prove oneself wise. Nevertheless, I have changed my opinions on the future of the city since beginning to study the city as a system. Here are two of my former beliefs and why I now consider them erroneous.

First, I had been led to believe that in the past the large city was often a successful machine for living and it was the automobile which caused the breakdown of the urban core by making suburbs possible. While it is true that the automobile increased man's mobility, it is not true that large cities of the past were successful before the automobile. Doxiadis[**] and Mumford[+] tell us that large cities periodically suffered breakdown and decay and that we find riots and slums in whatever historical period we seek.

Second, I held radial mass transit and elimination of the automobile would revitalize the city. I am now of the opinion that any rapid transit on a special right of way designed to articulate the conventional city and the suburbs may be an economic failure and may do little to rejuvenate the CBD. M.K.W. have made a very strong case, it seems, for the private automobile or, alternatively, a complete reassessment of the situation.

Let's attempt to set down some of the features which it appears will be operative in the future city.

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* I. Kristol in a review of P. Drucker's, *The Age of Discontinuity,* in *Fortune,* February 1969, p. 189.

**C.A. Doxiadis, *Ekistics,* Oxford University Press, New York, 1968.

\+ Lewis Mumford, *The City in History,* Harcourt, Brace and World, New York, 1961.

The high-density city is probably a thing of the past, but the trend to the suburbs will no continue to the point where a uniform density throughout a metropolitan region will prevail. Suppose we think of the city as the resultant of a number of social forces, some aiding each other and others opposing. The city initially grows larger and more dense because this growth is convenient to its citizens. Commerce and industry need workers and customers and these find it advantageous to live and trade near their work place. As the density increases, however, a trade-off point is reached. Land becomes more and more valuable in the city as economic activity increases. Eventually the worker finds it more economical to live outside the city, even though he must then pay increased transportation costs.

This trend was quite obvious even in mature and well-developed American cities following World War II, and the trend continued into the 1960's. The rate of family formation was high in the late 1940's due to returning veterans. These new families did not move into the tract housing of the suburbs only because they yearned to cut their own lawns, but because it was cheaper than renting. This fact seems somehow to have become obscured now that the trend toward suburban living has taken on a life and force of its own. Developers first moved outside of the city limits to find cheap land. Young families found that mortgage payments and taxes on the single-family houses they erected were cheaper than rent on an apartment in a multifamily dwelling within the city limits. Merchants engaged in retail trade and consumer goods soon followed to set up the suburban shopping center.

Clearly, it is better business to operate a single large store in the city than to proliferate many small stores with limited stocks into the suburbs. Hudson's of Detroit, one of the nation's largest department store operators, to take an example, repeatedly stated after the trend to the suburbs began in the late 1940's and early 1950's that they would never leave their huge department store in the city for small stores in the suburbs. And indeed today, when one wanders through downtown Hudson's with its acres of selling space covering 9 floors and a large city block, one understands the desire of the dedicated merchandiser to maintain this magnificent and variegated stock. Yet, once customers had moved to the suburbs for economical housing they found it too much trouble to make shopping expeditions on a regular basis to the city. Thus, Hudson's along with all the other retail merchants across the country, was forced by the competition to go to the suburbs. One must not suppose that this trend toward dispersion will continue unchecked, however.

I cite the construction of apartment houses in the suburbs as the first piece of objective evidence of a growing counterforce; though continued deterioration of the city and the continued popularity of suburban living may tend for a time to obscure this new trend. Peter Drucker urges that one must observe *international* trade to get reliable national economic indicators* because so much of the *internal* trade of a nation is warped by (possibly misguided) governmental policy. I would argue similarly that one must observe the small- and medium-size housing contractor to predict the future of the city. Government policy may direct urban renewal and mass transportation construction almost independently of economic reality, but the independent contractor cannot afford such detachment. Lately these independent contractors have begun to construct apartment houses on suburban land. First, we might find out why and, second, we should enquire if this is important.

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* Peter F. Drucker: *The Age of Discontinuity,* Harper and Row, New York, 1969, p. 66.

The answer to the first question obviously is that they can make more money with apartments. The cost of suburban land has increased 10 times or more in 20 years and the cost of construction is not far behind. Direct labor costs have not increased by a factor of 10, but suburban townships have increasingly placed restrictions on construction which have increased costs. Examples of restrictions where constructors must assume the cost are paved streets, curbing, gutters, sidewalks, and storm sewers. Thus a suburban home which cost $8,000 to $10,000 in 1940 would cost $40,000 to $50,000 in 1970; and the contractor who was mass producing $10,000 homes in 1950 is making $35,000 houses now and thinking seriously about apartments. This is an obvious way of reducing the per capita cost of land and other improvements required by the townships by increasing the density of occupation. Direct labor and materials costs are also reduced provided the apartment is three stories or less in height. The rent for an apartment is now becoming an economic bargain when compared with the cost of a house mortgage for a significant number of families for the first time in 20 years.*

Now we ask if apartments in the suburbs are an important indicator of some sort. Notice that apartment living in the suburbs is a contradiction in terms. One moves to the suburbs for "individual gracious living," for "privacy" on one's own "estate" whereas one moves to a city apartment for "cultural attractions," such as the theatre, restaurants, the "excitment of the cosmopolitan life."

It would appear that the marginal appeal of the city will increase if apartment living in the suburbs is the only viable economic alternative. One may hope that as city families realize escape to the suburbs is ruled out, they will devote their efforts to improving school systems and to civic betterment in the city. Just as one may argue that deserted streets cause crime in the streets rather than the reverse, the flight to the suburbs caused urban decay rather than the reverse.

This argument is not to say that one would expect necessarily a net inflow from the suburbs to the city but one would expect a decrease in net outflow and an increase in apartment and housing starts within the city. Thus, the relative density of the city with respect to the suburbs will tend to remain near its present level rather than continuing to decline.

On the other hand, I see no indication of a resurgence of the central business district. Business activities will remain disbursed. Perhaps Los Angeles, with its high-rise buildings in scattered clumps throughout the basin and no real central business district, is the model of the future.

The argument has another corollary. The marginal utility of growth of present cities is slight and there is no evidence that any structured reorganization presently envisioned (with the possible

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* This is not to say, of course, that many families have not placed larger value on other special features of apartment living, such as security and maintenance services, and chose apartment living in the first place.

single exception suggested below), can modify this fact. One could argue that the very fact we must concern ourselves with saving the city makes it clear that the city cannot be saved. Major growth will take place in cities which have not yet reached the equilibrium of forces mentioned above. A major social opportunity for the nation lies in organizing the form of new cities to take advantage of modern technology.

In arguing that artificial stimuli will not greatly affect the long-term course of urban development, I do not accept what may appear now as the inevitable nor do I wish to argue that a laissez faire attitude is the only determinant. Rather, I suggest that we must determine the causative vectors of urban development as objectively as possible and realign these vectors where they point improperly.

Take construction of city/suburban rapid transit versus the suggestion that a national high-speed ground transportation station be located in the city. The former is a palliative designed to treat the symptom not the disease, while the latter can be a functional structural change.

We have seen that rapid transit is unlikely to attract many workers who now commute to the city by auto. It would have some effect on shoppers but not an important one. The woman shopper from the suburb is even less likely to choose the transit line than her commuter husband. Legislation against the auto in the city will merely accelerate fragmentation of the city. Why is a high-speed ground transportation terminal different? Because the intercity business traveler now has a functional rationale for being in the city. Businesses which cater to out-of-town buyers will be attracted to the city, and home offices which send travelers to many points across the nation will also wish to be located close by the terminal. Hotels, restaurants, and entertainment will find an assured base for their businesses, and, as life returns to the city, we will begin to see suburbanites finding an attraction to shop and play there.

SUMMARY

In a previous paper I offered for discussion some possible goals for a national transportation system. I value this opportunity afforded by OCTA* to shift slightly the focus to the urban region. An attempt has been made to inbed the transportation problem into the question of the city as a system. Certainly no answers have been given, but I hope by my remarks to stimulate the interest of system theorists in the exciting problems presented by the world around us.

Donald F. Hornig, science advisor to President Johnson, struck a note of resonance with government officials and the American people when he criticized mathematicians who "seriously propose" that the public should support creative work "on the beaches of Rio de Janeiro or in the Aegean Islands." The public that pays the bill, Hornig said, "is not in tune with such colossal conceit."** I would suggest that systems engineers must also guard against intellectual conceit and be more concerned for the social relevance of their goals. We will not be forgiven for continuing to fiddle with $\dot{x} = Ax$ while Detroit or Boston burns.

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* Office of Control Theory and Application, NASA Electronics Research Center.

**Quoted in *Science,* January 31, 1969, p. 458.

WORLD BANK OPERATIONS IN THE LESS-DEVELOPED COUNTRIES

IRVING S. FRIEDMAN
The Economic Advisor to the President
International Bank for Reconstruction and Development
Washington, D. C.

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When I was asked to talk at this symposium, I told the Seminar Chairman that I was no expert in control theory; and it just seemed to be a little unfair to impose a non-expert in control theory on such a distinguished audience. I was told that an expert in control theory from the World Bank was not expected, but that the people working in control theory and in its various applications would be interested in the international scene and the World Bank as seen by an economist. The Chairman felt that perhaps I might indicate the kinds of problems that exist on the world scene which might not be so obvious to all of you, depending upon your particular preoccupation.

THE JOB OF THE WORLD BANK

The job of the World Bank is really concerned with the poorer countries, that is, with the less-developed countries. Our job at the Bank is to define the problems, to establish the goals, and to find and finance solutions in the fields of economic and social development in these poorer countries.

Normally, if you speak to development economists, they will speak in terms of maximizing output by maximizing the mobilization of resources and optimizing the utilization of the allocation of resources. This is, in general, what we try to do. But, as I see it, the emphasis is really on how we achieve a greater application of modern technology to the problems of the less-developed countries, using "technology" of course in the broadest sense of the word. It is obvious from this symposium that you take a very broad concept of technology.

Our job is to change current trends so that the gloomy forecasts of the world's future will not materialize. To me this is the essence of our problem. Our standard technique is to maximize the mobilization of resources and optimize their utilization. But in the real world we often have to be satisfied with less than the optimum.

When we look at what is happening in the less developed world, we make a subjective judgment--a judgment which we really can't prove in the end--that if current trends based upon the best forecasting techniques continue, we'll have a world that is simply unacceptable to people, say, 25, 30, or 50 years from now. The Bank, therefore, plays a major role in changing these trends; therefore, we have an interest in understanding the world economy as well as we know how--not because of a desire to understand its intricacies or to forecast better, but because we don't like the way this economy operates in the less-developed world and we want to make it operate differently.

I honestly don't know how much people here know about the less-developed world--I don't know whether you know what the World Bank is--so let me be panoramic and survey what is happening in the less-developed world.

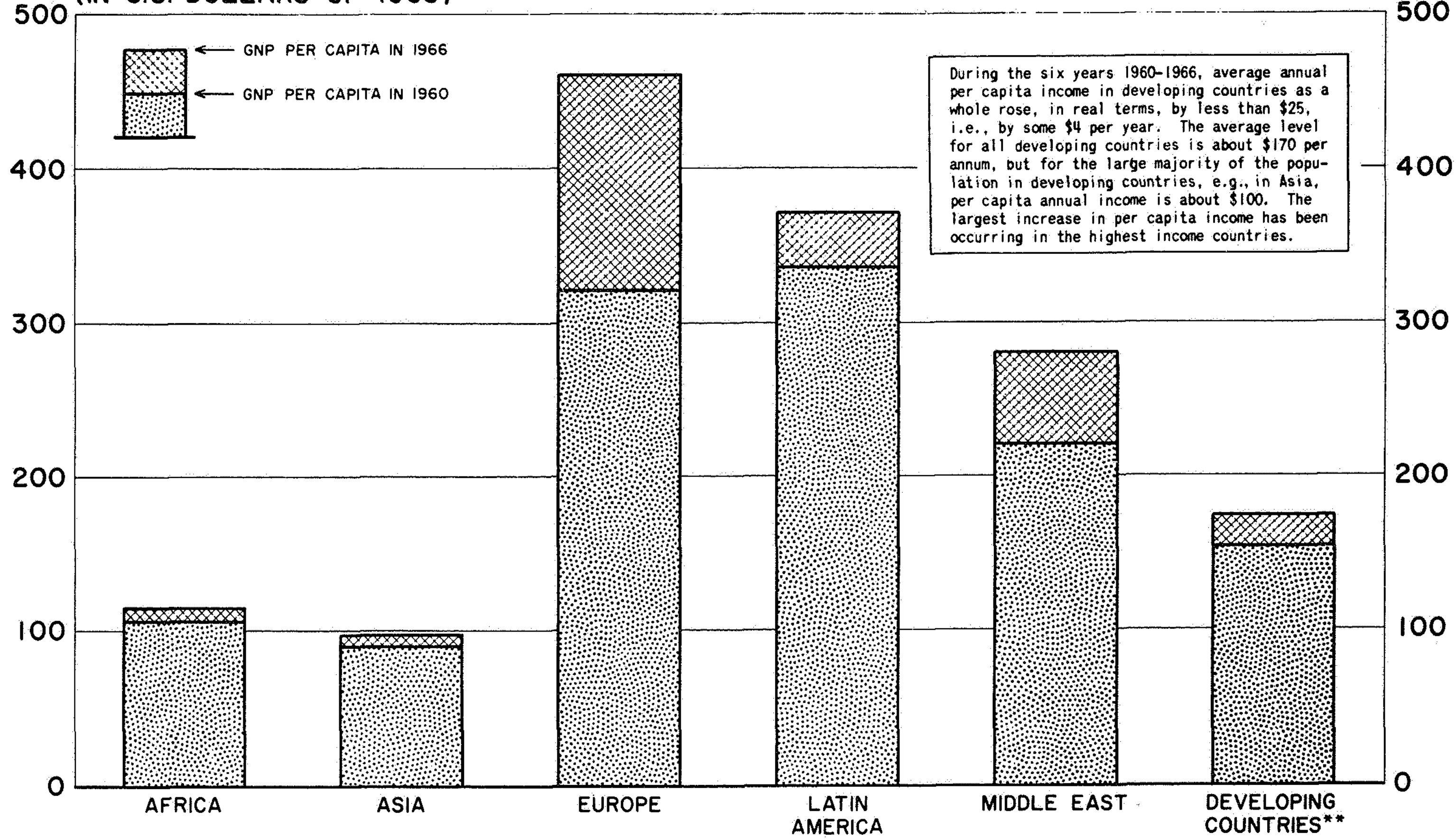
PANORAMIC LOOK AT THE LESS-DEVELOPED COUNTRIES

In the first place, the growth rates of gross national products (Figures 1 and 2) have been about 4-1/2 to 5 percent a year. As I'm sure most of you know, these are actually more rapid rates of growth than those experienced by the developed countries--Western Europe, Canada, the United States, Australia, New Zealand, and Japan. But one of the problems with the growth-rate statistic in the less-developed world is that we don't really understand what it means. We don't know whether growth and development are the same thing. (I believe they are not.) If you measure the increments in output from year to year, exactly what are you measuring if you're looking down the road to the year 2000? We often find these growth rates to be temporary. At times, we find the resource allocations that resulted in these growth rates were inefficient. Most important of all, we find that these increments in growth do not result in an increase of living standards for the great masses of the populations of these countries.

In terms of living standards, the gross national product seems to have little impact on the living standards of countries. This gives us a clue. First, let me point to population growth. The population growth in these countries varies from about 2 to 4 percent per annum. In Latin America it ranges over 3 percent per annum, if you exclude Argentina and Chile. So, you have a 4 to 5 percent growth rate, but at the same time you have a population growth rate in many countries of 2 to 3 or even 3.5 percent a year. It becomes clear that in terms of living standards, this means that the amounts available for increased consumption are very small indeed.

GROSS NATIONAL PRODUCT* PER CAPITA OF DEVELOPING COUNTRIES, BY REGION, 1960 AND 1966

(IN U.S. DOLLARS OF 1965)



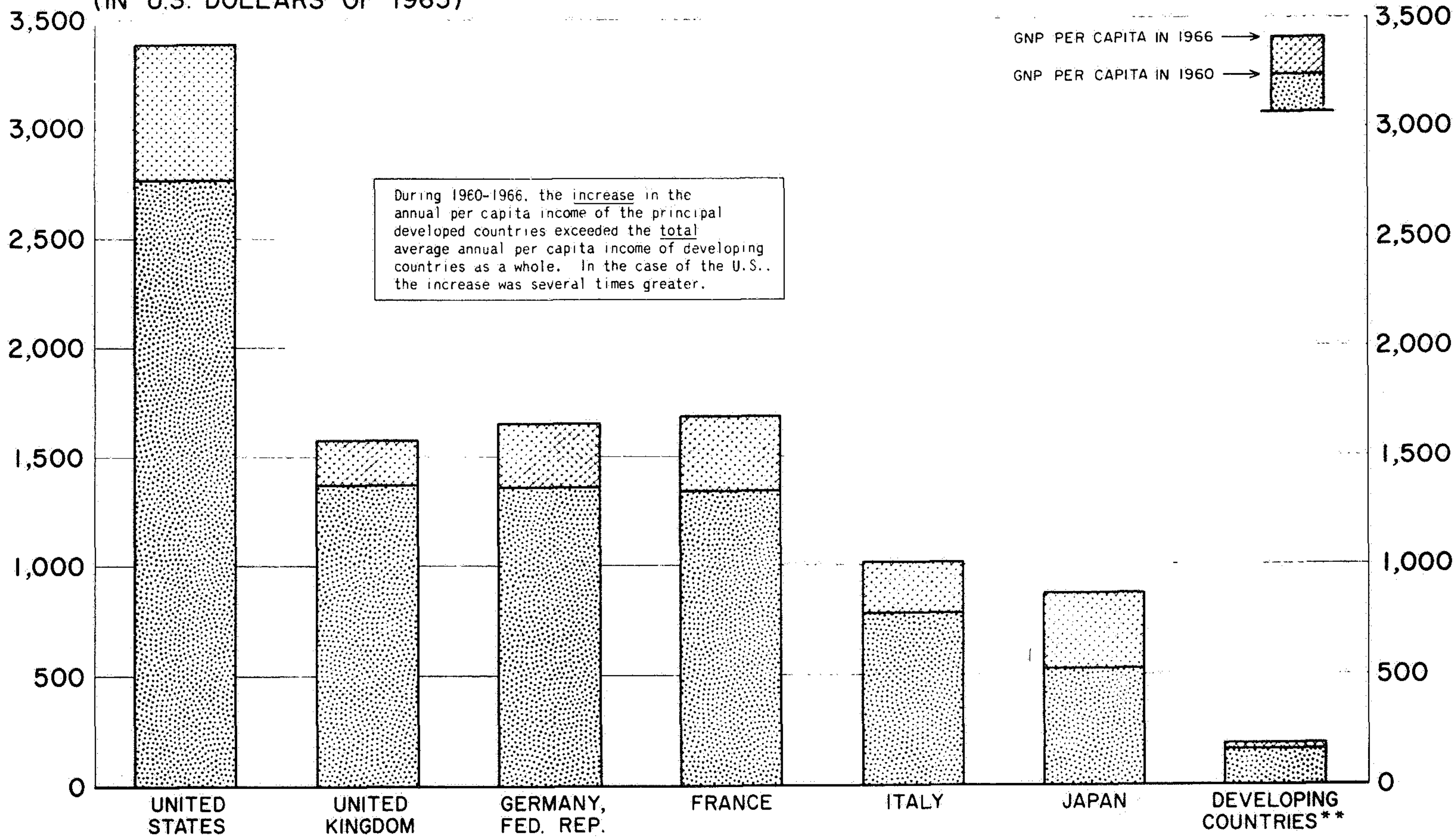
NOTES: EUROPE includes Cyprus, Greece, Portugal, Spain, Turkey and Yugoslavia. MIDDLE EAST includes Iran, Iraq, Israel, Sudan and Syria.
*Estimated GNP at factor cost.
**Data for developing countries cover 58 countries.
SOURCE OF DATA: IBRD

IBRD

Figure 1

GROSS NATIONAL PRODUCT* PER CAPITA OF DEVELOPED AND DEVELOPING COUNTRIES, 1960 AND 1966

(IN U.S. DOLLARS OF 1965)



*Estimated GNP at factor cost.
**Data for developing countries cover 58 countries.
SOURCE OF DATA: IBRD

IBRD

Figure 2

One thing that's obvious from our experience in economics is that a young population requires a high capital investment. I'm sure this is borne out in the experience that you've all had in your own kind of work. Therefore, when you have a rapid population growth rate in a country, you have a very high capital investment in terms of its relation to output. (We call this a high-capital-output ratio.) You need schools, you need roads, you need improvements of water supplies, you need improvements in medical facilities, you need improvements in "social capital." But, in terms of the gross national product or other consumption standards of the community, we see no reflections of these increases in social capital for years, even decades. You can point to the fact that people are healthier, but this doesn't show up in consumption standards.

Thus, what we have seen in the less-developed countries is a very small rise in the average consumption standards. More significantly, if you forecast present trends in gross national product along with present trends in population, there will be virtually no increase in the standard of living of people in the poorer countries of the world in the next 25 years. They will be living essentially the way they live now (Figure 3). Now, of course, you're going to have more highways; you are going to have more hospitals; you are going to have more of the modern technology; but in terms of the things that go into the breadbasket--into the consumption standards--you are going to see little change.

I'll now give you a very familiar statistic. It is generally expected that in the world of 2000 (Figure 4), which is within the reach of virtually everyone in this room, we expect to have about 6 billion people--our demographers tell us between 5.5 and 7.0 billion. If you take 6 billion people, we would say it's a fair guess that between 4 to 4.5 billion of this 6 billion will be living at a per capita annual income of between $100 and $200 per year in real terms as compared to the $2000 and $3000 found in the developed world. We've all had some training in statistics, and we appreciate the lack of comparability of these statistics. I'm not at all sure these figures mean that someone in the United States consumes 30 times as much as someone in India. But, it gives us some indication of what we're up against.

THE INADEQUACY OF CAPITAL

If we try to change this future, we find one of our basic problems is the inadequacy of capital in the less-developed areas. Whether you think in terms of fixed capital, the public sector versus the private sector, or human capital, I think one thing happening in economics--which has been going on for centuries, but which has become now dramatically clear--is that the capital endowment of a country has become more important than the so-called natural resource endowment of a country. Capital availability is a lot more important than what you can add up in terms of palm trees, rubber trees, or black earth.

At first it is surprising, even baffling, that countries like Indonesia or Brazil, which have resource endowments comparable to any place in the world, remain underdeveloped. For various historical reasons, the availability of capital for production and the availability of the right kinds of human beings for production are very, very scarce indeed. These are the real problems.

Now, how do we overcome these problems? The economist thinks in terms of investment: investment in fixed capital and investment in human beings. We find that 80 percent of the new investment in these poorer countries comes out of their own domestic resources. Now, this is 80

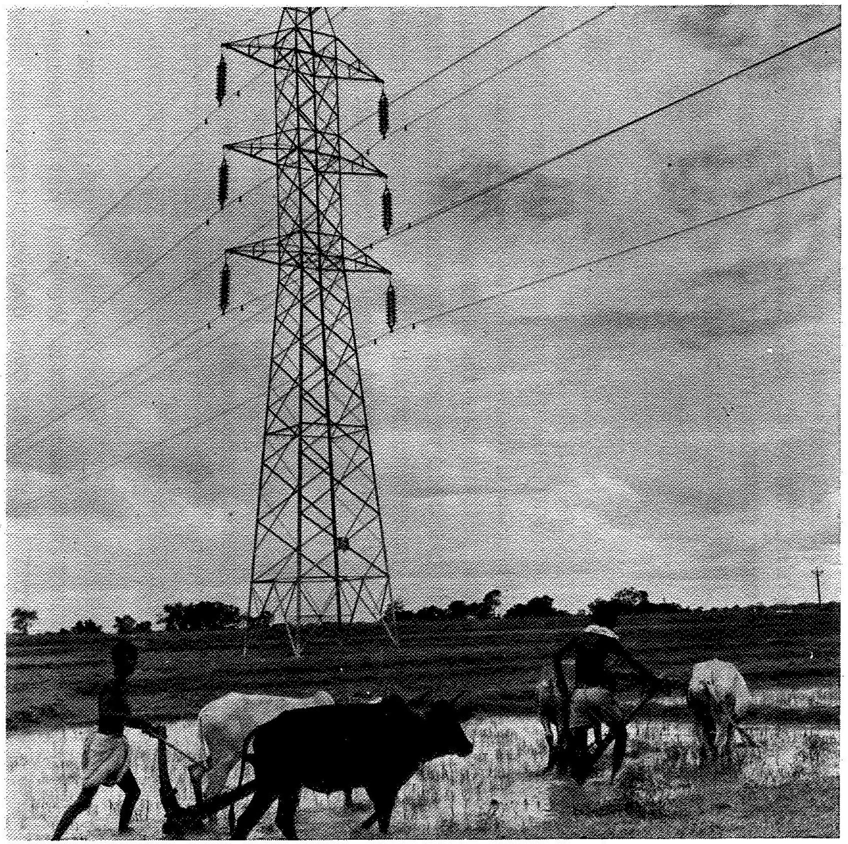


Figure 3 - India is now carrying out the third in a series of five-year plans to raise the living standards of the Indian people. The first plan, 1951-56, involved total investment in economic development, governmental and private, equivalent to $7,000 million. Investments in the second plan were over $14,000 million equivalent. The third plan, 1961-66, requires investments approximately equal to those of the first two plans put together. The WORLD BANK's lending to India now amounts to $850 million, making India the BANK's largest borrower. In addition, the International Development Association, the BANK's affiliate, has made credits to India of development finance, particularly for India's railways, for private steel production, for electric power supplies and for agriculture. The Damodar Valley is rich both in farming and industry. These Indian farmers benefit from an irrigation system provided by the Damodar Valley Corporation, which also operates the power complex for the entire Valley.

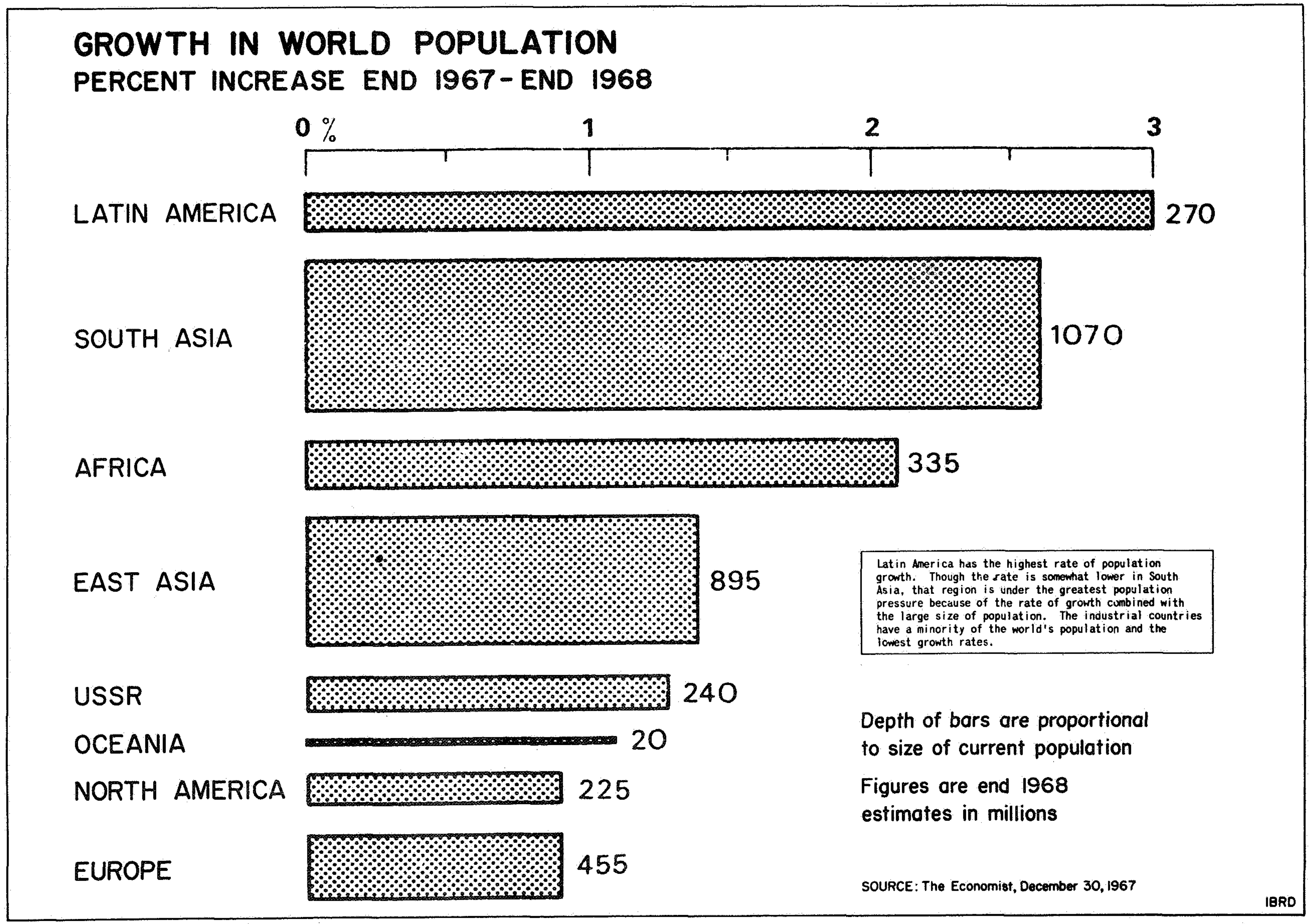

GROWTH IN WORLD POPULATION
PERCENT INCREASE END 1967 - END 1968
0 %
1
2
3
LATIN AMERICA
270
SOUTH ASIA
1070
AFRICA
335
EAST ASIA
895
USSR
240
OCEANIA
20
NORTH AMERICA
225
EUROPE
455
Latin America has the highest rate of population growth. Though the rate is somewhat lower in South Asia, that region is under the greatest population pressure because of the rate of growth combined with the large size of population. The industrial countries have a minority of the world's population and the lowest growth rates.
Depth of bars are proportional to size of current population
Figures are end 1968 estimates in millions
SOURCE: The Economist, December 30, 1967
IBRD

Figure 4

percent in countries where the per capita income is between $100 to $200 per year. Indeed, in Latin America we find in countries, such as Brazil, that closer to 90 and 95 percent of the investment is coming out of their own resources. This gives you some idea of what the prospects are for the future and why these forecasts are so bleak. You can see why I say standard growth or consumption-oriented forecasts are, from many points of view, unacceptable as indicators of what is actually going to occur in the future. Something is going to change the trends. As scientists we know that there are options, alternate choices, agreeable or disagreeable. Control theory helps us decide intelligently. Unfortunately, it doesn't quarantee that superior intelligence will guide decision-making. It is our task to remedy this defect.

UNEMPLOYMENT IS RAMPANT

Now, combined with these constraints on their investment effort--this dependency on adequate domestic resources--we find that there is also widespread unemployment. It would be unbelievable in the United States or any of the developed countries, but in the less-developed areas they don't talk about whether or not you can run an economy with 3.5 percent unemployment versus 5, versus 3 or even versus 2 percent in some European countries. You have overall unemployment rates of 10, 20, 25 percent of the working population in these countries. Yet, at the same time you have the paradox of a shortage of the kind of labor that is needed for breaking the many bottlenecks in the application of modern technology. Factories don't get started because there aren't enough of the right kinds of people to work in them at the same time that there is mass unemployment. Of course, as pointed out in a number of the replies to the OCTA* questionnaire, the very introduction of modern technology has aggravated the problem of unemployment. The Volta River Dam, in Ghana, made possible a large aluminum processing plant. If I remember correctly, the whole thing is run with a handful of people. When you introduce a very large capital investment, you may be actually aggravating the employment problem. You may actually have destroyed existing employment opportunities and replaced them with something that simply does not absorb the unemployed people.

INSTABILITY: ROADBLOCK TO PRIVATE INVESTMENT

Adequate external capital for the less-developed countries is simply not forthcoming. For a variety of complicated reasons, our private industry is interested in only particular kinds of activities overseas. If a country is capable of producing petroleum, it has no problem in finding foreign capital. If it is producing copper or tin, it will also probably find people interested. If a country has a stable political environment and a good geographical location, it may find private capital for tourism or even manufacturing activities. But for the less-developed world, for reasons which are inherent in the prevailing economic and social situations, private capital is scarce.

A principal reason for reluctance on the part of private capital lies in the explosive instability generated in the poorer countries by the introduction of modern technology. These countries have generation gaps not due just to age, but for the reason that people cannot communicate with one another because of the impact of modern technology, the educated and the

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* A questionnaire sent out by NASA ERC's Office of Control Theory and Application (OCTA) in 1968 soliciting comments on the status of the control field and potential future applications of control research and technology.

uneducated being two different cultures. Whole cultures are being subjected to near pulverization by modern technology. I'm not saying this is bad; I think much of it has to take place. The cultural standards of these people, in the end, have to adapt themselves to modern technology, if they are to break the vicious circles that they now live in. But because of this social and political instability, it is very understandable that a private entrepreneur, who finds investment opportunities all over the developed world, does not wish to invest money in high-risk areas. Why would he be interested in going to a country characterized by social and political instability? If he asks his economic advisors about the likelihood of the country stabilizing and if they're honest with him, they will tell him that it's probably going to get worse before it gets better. The entrepreneur has to be a man of exceptional courage and vision to see advantages in such situations.

You look next at the public capital which might respond to this situation. We find that the flow of public capital to these parts of the world is really not very large despite the publicity it gets. The net outflow of public capital from all the rich countries of the world to less-developed countries is about $7 billion a year. All of the public capital that goes to the less-developed world is shamefully small when compared to the activities of just a few of the corporations represented in this room.

GREAT EXPECTATIONS IN THE LESS–DEVELOPED NATIONS

The problem of trying to get more public capital into less-developed countries is not easy. It's not a problem of lack of morality or even--in my opinion--lack of understanding. There are very profound reasons why this public capital has not been as large as you might expect it to be, and much smaller than could be used effectively in the less-developed world at the present time. Part of the problem is that this less-developed world has come on the economic scene very, very late. They have inherited all of our modern concepts; an awareness of what life can be like. Not only do they see visible demonstrations of our way of life, through television, through the multilingual editions of *TIME Magazine* which they can look at--they can't read, but they can see the pictures; not only can they see this other kind of world, but their trade union leaders, their political leaders, and other members of their community have told them that if you're unemployed you're supposed to get paid. If you need medical care, you're supposed to be helped. If you reach old age, you're supposed to be helped. Even in an economy like that of the United States, these expectations have raised questions of feasibility. Imagine what this does in an economy where the gross national product per person is $50, $100, or $200 a year and political leaders are trying to implement welfare concepts which have developed in rich economies. Please don't take this as an indictment of welfare programs. I just point to the kinds of problems we're dealing with and their consequences.

In places like Argentina or Brazil, once a man has a job it is most difficult to get him off the job. A job is a precious thing when he's confronted with mass unemployment; and the job may have built-in pension rights, medical benefits, and unemployment insurance.

Some of you may have heard of the Argentine Railways. The deficit on their state railway system was, until recently, equivalent in monetary terms to all of the net foreign capital they obtained in any one year. The railway deficit was equal to the entire balance of payments deficit. The Government could not get rid of the excess labor supply. For years it was nearly impossible to fire anybody who had a job on the Argentine railway system, regardless of the kind of government. The railway system itself was fantastically inefficient. It was often faster to walk then to take a train. And if you wanted to take cattle to market, you didn't take them on the train because they would simply starve. Fortunately, this particular situation is greatly improving. Until recently, however, this immobility of labor was a great problem for any economic activity. If you spoke about the industrialization of Argentina, you had a bear by the tail. How did you break this pattern? How do you change the fact that many people would just as soon not work elsewhere? Cases were reported of workers not even reporting for duty because their train was not going to leave. They got paid anyway, and life went on. In the meantime, they used their pay to open up little shops on the side to augment their incomes. How could you introduce a factory into Argentina under these conditions?

When I talked to some of their industrialists, they would say, "Look, given the problems of opening a factory in Argentina, you would do better investing in the New York stock market. You have brokers in New York and some very fine investment counsellors; they're doing all the work and you're making the money." I cite this past Argentine problem because it is a vivid example of realities in many developing countries--some more dramatic in many ways, but not unique.

One of the things we ought to recognize is that we are dealing with societies which are often not managed efficiently from an economic viewpoint. Even with all the difficulties of management in the United States and Western Europe, there is just no comparison with the lack of control in the scientific sense of the word in the less-developed countries. This is why it is so interesting to me to have modern technology consider control concepts applied to the problems of the less-developed countries.

NATIONALISM HAS RUN WILD

What are the solutions to these problems? One of the reasons I am here today is that no one has found the solutions yet. We need all the help we can get from control theory and experience in finding more effective ways of coping with these problems. Perhaps it might help if I elaborated somewhat further on the problems. Cutting across all of the instability mentioned above is a world in which nationalism has gone wild. We all believe in President Wilson's dictum of national independence and self-determination; but we have no concept of the relationships between economics and social viability, on one hand, and the desire to be a nation on the other. Nationalism is out of control.

What do you do about each tiny new country? Of course, it's easy--easy, because in terms of population they are way down there. You don't worry too much about them. You're much more concerned about the other extreme: a country like India which is not a country; it's a planet in itself (Figure 5). It's got about 500 million people with more cultures than anyone has been able to add up; with 14 official different languages and hundreds of important dialects; with a veneer of communication among a very thin layer of people who know the English language. You have what I call "planetoid economy," where it isn't a question of just a few people; you're trying to achieve social and political stability, cultural transformation, and acceptance of modern technology in nearly one-sixth of the human race. India now has a per capita income of $100 per year, and it has had no significant increase in its standard of living in the last 20 years. There are many who would claim there has been a lowering of its standard of living. What are you going to do with India when it grows to a billion people? And it's going to be just that within the foreseeable future.

Figure 5 - Women washing clothes in the river in front of the Bokaro thermal power station in the Damodar Valley of India, which was built by the Damodar Valley Corporation with the aid of WORLD BANK funds.

We don't know about communist China. It's not one of the Bank's member countries, but I suspect that the situation there may be even more difficult than that of India because they have the additional problem of being even bigger. The biggest countries in the world are less-developed countries. We don't have a developed country that has 500 million people and no one has yet figured out how to govern effectively or efficiently 500 or 600 million people within one political unit. Yet, this is the frame of reference within which these countries have to operate. I hope this gives you some idea of some sort of introduction to the world in which the Bank operates.

HOW THE WORLD BANK OPERATES

The World Bank consists of three rather confusing organizations. There is the World Bank proper, which is the parent organization; it is essentially a banking institution. It's based on capital subscriptions by its member countries and has a total capital subscription of $22 billion. The operations of the Bank involve somewhat over $1 billion of new loans per year. We're probably going up to about $1.5 or $2.0 billion in new loans in the foreseeable future. Our lending is more or less conventional, which means it's based upon 20- and 25-year loans, which are related to the economic ability of the country to repay. It's essentially a bank in the sense that we don't make loans if we don't expect to get repaid, and we charge 6-1/2 percent interest. Our customers are among the richest firms in the world; namely, the less-developed countries or private borrowers within these countries able to obtain government guarantees.

The International Development Association, IDA, was formed because it was recognized that some countries were simply too poor or too much in debt to be able to pay back loans from the World Bank. IDA extends interest-free loans of 50 years, in which nothing is repaid for 10 years, one percent of the loan in the next 20 years, and the last of the so-called "credit" in the last 30 years. The World Bank has existed since 1946. IDA has existed only since 1960, so we haven't gotten into the period of repayment of IDA credits. Incidentally, the bulk of the funds used by the Bank consists of funds that we borrow in private capital markets. We borrow in the rich countries, and we act as a conduit to the poorer countries. This year, for example, our own borrowing operations will total well over $1 billion. Most of our borrowing this year will be in Germany. We will use these funds to make loans to the poorer countries.

Another source of Bank funds consists of the repayments on past loans made to these countries. They, of course, have to amortize their debts, and they have to make interest payments.

There is a common misconception that the United States provides the monies for the World Bank. In terms of monies actually used, considerably less than half--closer to 25 percent--of the actual monies disbursed by the World Bank find their origin in the United States, either from the private capital market or the U.S. Government.

IDA, however, receives funds from government budgets. Here, the United States provides about 40 percent of the total contributed. In addition, we in the World Bank contribute a substantial sum from our own profits. This year it is $75 million. The scale of operations of the International Development Association, in the near future, will be hopefully about $500 to $600 million a year.

We also have something called the IFC, which is an investment institution. We sometimes refer to it as our "private" arm. Its main function is to try to provide seed money and encourage private capital both in the rich less-developed countries to start new enterprises in the less-developed countries. The IFC starts new enterprises that would otherwise not get started and expansions that would otherwise not take place.

WHAT WORLD BANK TRIES TO DO

I think we could all agree that changing the trends mentioned earlier involved technological change, including new government institution building, new types of highway administrations, new types of water-control administrations, new types of city managers, and so forth. But the problems of achieving this technological change are political, social, and cultural. Perhaps this is where we begin to differ from the problems with which you gentlemen deal. We can't bring about the changes we're talking about without social, political, and cultural transformation. Thus, the problems cannot be isolated from the main cultural, political, and social streams of the country, difficult and unstable though they may be.

For the economist this is a fascinating problem, of course. It goes back to the problems that created the discipline of economics. Economics originated as a "dismal" science; and now we're again confronted by dismal problems and outlooks. We dealt with the problem of scarcity from the beginning, and now we deal with the problem of scarcities in their most acute forms. As an economist I am most interested in the kind of work that you gentlemen do--the kind of thinking you do--because perhaps your kind of thinking can help us understand better how to mobilize resources and how to allocate them more efficiently. The mistakes or suboptimal decisions imposed upon us by the cultural, social, and political situation in which we have to operate may be compensated in part if we can control our efforts better. We want to know about optimal decision-making, and at least understand what an optimal decision would be; but we know we're going to keep making suboptimal decisions. But mistakes should not arise from inadequate knowledge, inadequate theory, or inadequate models, because these things we can work on. It is possible to improve our understanding of the problems. Many of us who work in the Bank feel that the kind of work that you're doing, if applied to our problems, could make a great contribution in helping us to change the current trends we see as unacceptable to the world.

SOME AREAS FOR QUICK ACTION

What are some of the key problems with which we deal? First, how do you improve the economic and social performance of governments? How do you make countries like Brazil, Argentina, India, or Malaysia adopt better economic and social policies?

Important things, such as road building, need no spelling out here. However, what looks like a minor change in overall national economic policy may be much more important than all the investment activities of the World Bank in that country in any one year--a change in the tax structure that helps mobilize more savings and induces the use of mobilized resources for productive investment. A change in the so-called "exchange" rates for the country's currency, which determine the prices at which exports can be sold, may have much more to do with the ability of the country to earn necessary foreign exchange to buy the capital goods it needs for investment than the investment funds that you can provide from external services.

Take bigger things--take the defense programs. As we look at these less-developed countries, a number of them have a considerable fraction of their gross domestic products invested in defense establishments. The defense budgets are at times bigger than their educational budgets. Speaking to NASA, speaking to you as a U.S. group, one doesn't have to spell out how important the defense expenditures can be. But remember, in the United States you're talking about defense expenditures relative to the kind of economy we live in, the kind of productive capacity we have. But when you talk about defense expenditures in a country such as Peru or Pakistan (Figure 6), it's not only just a question of whether they have aircraft or not. Here are countries where they can't get the literacy level up above primary school, except for a small fraction of the population. Yet, they have defense budgets considerably greater than those allotted to primary school education. Why do they have these defense budgets? In some cases, of course, it's obvious why they have them; it is because they have real defense problems. In other cases you find it's because they have had admirals and generals around for a long time, and they are considered part of the culture. Thus, such countries find themselves caught in cultural patterns. You need to talk to Admiral So-and-So and ask him, by the way, what do you need all this stuff for? Wouldn't it really be better to put the money into technical education? One of the extraordinary things in Latin America is the extent that the military is often in the forefront of the field of economic development. Often it seems easier to talk to them than to many other groups. A number of them are really very forward-looking in their recognition that some of their expenditures must be cut back if their countries are to progress.

A more subtle performance factor involves taxes. The Government of the Philippines, for example, at one stage was trying to pass a small increase in taxes for four or five years. They could not get their Congress to pass the tax bill, though it was not large. Finally, it was passed but the delay was costly to the country's development. When their government puts up a tax bill, some countries will actually say to us, "Please don't give us any money until we pass a tax bill, because one of the few things we can say to legislators is that, if we don't pass a tax bill, we won't be able to finish that road."

It would be very interesting for this group to prepare a paper just on the question of performance criteria. How do you judge a country's economic performance on the national economic policy level? If you're sitting in an international organization and interested in the allocation of scarce resources and development capital, you want to do the most you can for your members. You are often driven to the point of saying, "Look, if a country doesn't do enough for itself they're not going to borrow from us; we're not going to lend our scarce resources to it." But, how do you go about judging economic performance of governments in this great variety of human experience that we face? We're looking for objective criteria because, as an international organization, we know if we say *no* to Country A, and to B we say *yes,* we ought to be able to explain why it was *no* to Country A. If we had quantifiable criteria, we'd be able to explain these decisions to countries.

We have a list of things we consider, but it is not precise and cannot be regarded as something you gentlemen would call "criteria." So we're driven back to making "seat-of-the-pants" judgments about whether performance is satisfactory or not. This is not done by intuition. We devote tremendous effort in learning as much about a country's economy as possible, in learning the constraints, in forming judgments about its various sector investment possibilities, in estimating what it can do in the field of savings, and so forth. We aren't trying to duck the responsibility of making the judgment. What we're groping for is criteria; this is why system analysis and control models are intriguing to us.

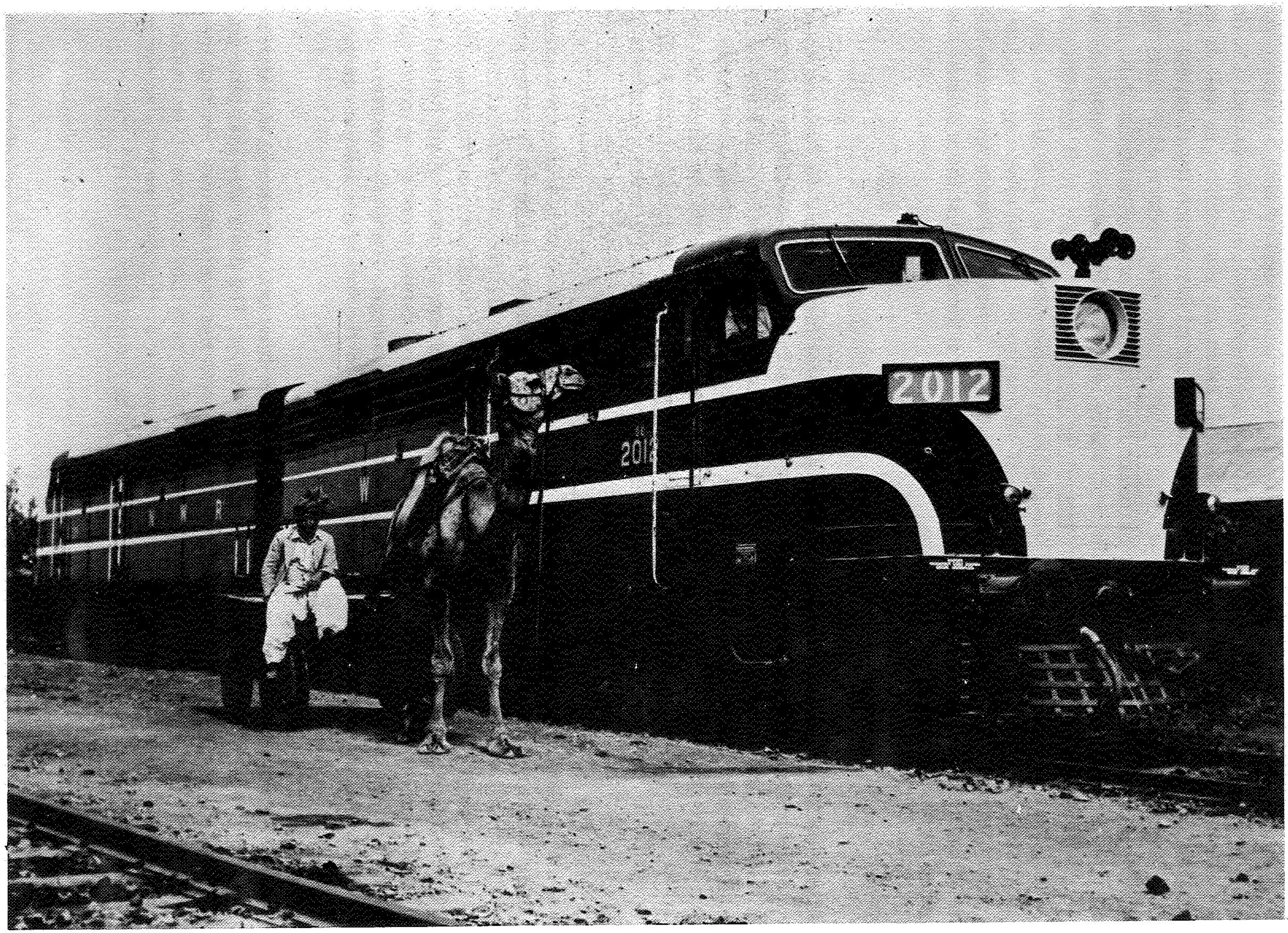

Figure 6 - The old and the new -- A camel drawn cart with his Pakistani driver stops beside a modern diesel electric locomotive in Karachi, Pakistan. This locomotive operates on the North Western Railways in Pakistan and is one of many similar locomotives purchased for Pakistan with the aid of funds from WORLD BANK loans.

A concept I think should be interesting to a group of this kind is that of *credit-worthiness.* When anybody borrows, they have to pay the loan back. When you're dealing with a government, you have a peculiar kind of constraint. A government promises to pay back, and you expect it to do so. Now, in ordinary business relations, there is the risk taken by the creditor as well as an obligation assumed by the borrower. We have a sophisticated set of laws which try to ensure the repayment. If there isn't a repayment, however, you try to protect the creditor who made the resources available in the first place, but the borrower may find all sorts of remedies if he has legitimate difficulties. But, these options do not really exist in international relations. In international relations, if a government borrows, it is expected to repay. If it defaults, its credit-worthiness plummets. Even a so-called "rescheduling," which is just a stretching out of a debt, is an act of great importance because, in terms of international financial relations, a country that has to stretch out a debt immediately becomes a dubious borrower. People are concerned about whether or not they ought to make more loans to them; and these are just those countries in desperate need of capital.

THE ECONOMIC CRYSTAL BALL

When we judge a country's ability to repay a long-term debt, we try to evaluate these countries as they're going to look--not now or the next 5 years--but 5 to 25 years from now when they're going to be repaying this debt. When you try to forecast the external economic behavior of a country between 5 and 25 years from now, some economists simply throw up their hands in horror and say this is utter nonsense; they say a forecast like this isn't worth the effort. On the other hand, some of us, including myself, feel that, if you don't try to make such forecasts, you're just really flying blind. You have to do something, even though you recognize the limitations of what you're doing.

So, one of our most intense efforts at the present time in-the Bank is trying to improve forecasts of the external sector of the economy. What techniques would help us do it better, and, more challenging, if you don't like the forecast, how do you change it? You often find a situation where you look at a forecast--even one made under favorable assumptions--and you find, say, that exports are growing more rapidly than the historical trend. Nevertheless, the country will run out of its repayment capacity, although you know that its need for external capital is not going to run out. You know that it's going to need more and more capital as it develops. Therefore, somehow you have to devise a mechanism where it can borrow more money in the future despite your original forecast.

We work on this problem in two ways. First, you ask how you can change the internal economy so that the forecasts of the internal economy will change. The other way asks how you change the attitudes of the so-called "creditor" countries towards this needy country. Perhaps they can be convinced to alter their criteria, their lending terms, or perhaps they can open their markets more widely to the exports of the developing countries. However, a constraint we fully accept in the World Bank is that, if we make a loan, we surely have to be repaid because the returned monies are needed by some other poor country.

PRICE FLUCTUATIONS AND OTHER PROBLEMS

In discussing the fluctuations of export prices of the raw materials sold by these poorer countries, the question is: Can you set up a control mechanism to prevent these fluctuations from disturbing a poor country's economic development? There are all kinds of fluctuations: random fluctuations; fluctuations of a cyclical nature; long cycles related to the structure of production; and so forth.

We have also set up a separate group in the Bank to work in urbanization because we appreciate the fact that some of the most severe urban problems in the world exist in these less-developed countries. For instance, metropolitan Buenos Aires includes nearly 8 million people. You have nearly half of the population of the whole country living in one metropolitan area. Consider Rio De Janeiro, Istanbul, Calcutta, Madras, Bombay--if you'd just go and look at these cities you would understand, without knowing the statistics, what an urban problem really is. How do you solve the urban problem when you don't have the national income you have in France, Germany, the United States, or England? There is no revenue base to tackle these problems. You don't have the skilled personnel for a systematic attack on the problems of urbanization. Therefore, we're very interested in the work that's being done on urbanization in the United States. How do you do it with the least personnel, with the fewest uncertainties built into the system?

GOOD DATA ARE HARD TO FIND

We carry out our work with complete recognition of the crudity of our data. To call them "data" is often misleading. Sometimes they are not even as good as daydreaming. You just find some poor official and tell him to put down a number; so he puts down a number. We're asking them for data about subjects his people never cared about. Take population, for example. In the past, in most of the less-developed countries, the community couldn't care less if somebody were born--it was a family or tribal matter. In some cases, it has been only a police matter; that is, they'd like to know how many people live within a given civil jurisdiction. Therefore, some record may be kept. Sometimes it's a church matter. The church would like to know whether it has a growing population in a particular parish. As for people dying, that's of no interest except for the disposal of the remains in a decent manner. The vital statistics gathered at census times have no relation to those needed by someone working on family planning needs. They reflect no concept of whether population growth is a function of income, social background, employment or unemployment, or urbanization or non-urbanization. All you get out of the vital statistics is a bare number. Census statistics usually tell only how many births and deaths there were that year; sometimes in a more advanced economy, you learn whether they died from diseases or accidents. This situation exists because these cultures never intended to do anything about population; why should they go around collecting relevant data.

In sharp contrast, in the monetary field, the data are frequently superb. People have been interested in money and banking for centuries--even in these poorer countries. All countries are interested in what is happening to their short-term price movements, their external financial position, and how these things might be influenced by changes in the money supply. Thus, most less-developed countries have central banks. In fact, central banks in most less-developed countries were just set up entirely for regulating money supplies. Sometimes the banking system ends up having the only systematic collection of trained people. They're trained only in short-term phenomena. Nevertheless they are well-trained in something practical, whereas the other agencies of government need few skilled workers. They need people to clean streets, to keep the railway passages clear; they've never developed large trained staffs.

Consequently, monetary problems constitute one of the few things we can learn about in less-developed nations. For example, we can get the statistics of what's happening to money in Brazil; but in these cases knowledge does not automatically infer adequate public policies.

We try to make up for the crudity of the data by sheer hard work. Countries get impatient with the World Bank. We probably ask more questions than anybody else. We take the longest time to make an economic report. We're never happy with the economic report. We revise it all the time. We're sending people out all the time. It's because we always feel we haven't yet reached the understanding of these economies we would like to have in order to participate in the decision-making which greatly affects these countries.

SOME CONCLUSIONS

I had planned to mention other aspects of World Bank operations, but time does not permit this. However, the kind of conclusion I come to is obvious; we must prepare for a deliberate attack on these trends I've been talking about. In that sense the future must be programmed, planned, controlled--call it what you will. We run into the same semantic problem you do. Words like "planning," "programming," and "controls" have certain connotations which, for many public policy makers, are completely misleading. When I use these words I think I use them in the same senses that scientists and engineers use them.

The free-market mechanism is as much of an instrument of control as "collaborative economics." When we use the word "control," we aren't throwing out the free-market mechanism, as many people think we are doing. We have this problem all the time. When we speak about wanting to do more work on programming or control theory, some say, "My heavens, you mean you're going to export socialism around the world." I'm sure you've had the same problem. Secondly, I think it's important for us to keep in mind all the time the importance of realistic time horizons. I think one of the fatal errors and blunders made in the field of international development and finance is the use of false time horizons. I don't know whether they are deliberately false, in the sense that people thought that it was better to advocate a false but more acceptable time horizon to a donor of funds, or whether it was a fault in theory and analysis. I don't know and don't really care about the past. What I do care about is getting across to the people a realistic time scale of when you really can expect things to happen based on what you're doing. If the time horizon is 50 years for change, or 100 years, you ought to be willing to tell people that. Time horizons should come out of economic analysis, not out of what your listener wants to hear. In our field this is particularly important because the so-called "disappointments" that you read about over and over again in the less-developed world are frequently only disappointments in time horizons. Someone will go to a legislative body and say that in 5 years a country will have self-sustaining growth. There was no more chance of that country having self-sustaining growth in 5 years than I have of living to be a million. That country couldn't have self-sustaining growth independent of net imported capital in any foreseeable future; and yet such statements were made repeatedly.

It's important that we have realistic time horizons, because those who provide the needed funds and those who give the public leadership during the difficult cultural transformations transpiring within these countries must know what they're doing. They mustn't be put in the position of making false promises because we have given them false assumptions. I know there are ranges of error, but ranges of error we can understand. They're usually completely different from the kind of time horizons tossed about loosely in our field.

Another thing I'd like to emphasize is that preference targets cannot be dictated by anybody from the outside. They have to come from the cultures of the less-developed countries themselves. There is no point in setting up a model for an economy which builds in your own preferred targets. You are wasting your time. In that sense I am critical of certain models made in this field. There's no point in making a preference target for an economy that contemplates making everybody in the country different from what he is virtually overnight. When you work out a preference target, you have to use your economic knowledge and your persuasiveness to get the country to give a higher scale of preference to those targets you consider important to the economic and social priorities of the country. In the end, that country is going to have to decide and, if it doesn't agree with you, you've engaged in a paper exercise, even if you achieved some understanding.

I'm personally very interested in this whole theory of suboptimal decision-making. Since we can't make optimal decisions, how do you go about making suboptimal decisions? I've read some of the literature, but I'm baffled. How do you go about systematically making suboptimal decisions so that you don't end up with--that word you use in technology--a "dodo?" The whole economy can become a dodo as well as a printing press. This is to me a very important question.

The last point of all is that we have to learn how to pose the new questions which basically query our premises. In national economics, particularly in the development field, we are so aggregative and we see things on such a general level that we appall anybody who deals thoughtfully on the micro-level. In investment theory or production theory, things that are regarded as variables we regard as constants. For example, take capital output ratios; you who work out production functions know you can vary labor and capital. We often use them as constants. We often use the marginal savings rate as a constant. Similarly, marginal propensities for import we may keep fixed. We know that these factors are actually variables; but when we start to build aggregative models, we find that we sweep their changing characteristics under the rug. The result, I think, is that we never ask the right questions. We ought to be asking how to change that capital output ratio. Let's start the inductive research necessary to get this knowledge. Let's find the pertinent data. If we don't get the pertinent data, let's use some incentives to get the data. Countries don't want to stay ignorant. If you point out that you have to know something, they're willing to collaborate, particularly if you're willing to help them do it--which in many cases we are. Often they're quite happy to put their unemployed or underemployed university graduates to work with you on some of this new research. But they'll never do it unless we question our own premises; unless we ask them the right questions; unless we are willing to seek new relationships.

These are the kinds of things we're doing in the Bank. I'm afraid they have been only partially stated, but I hope I have given you some idea of the sort of things we're trying to do in our institution. Thank you for listening.

FLOOR DISCUSSION

Dr. J.L. Shearer: I don't know if it's a question or a comment. I'm trying to sort out a lot of things from what you've said. It seems to me that the role of international trade in all of these efforts to help a country develop or to develop itself is a very crucial thing, and it would be perhaps the only thing that might come in this category of telling them what to do. But isn't it true that you always come back to this as a kind of common denominator, that you're always looking for ways in which they can develop some aspects of their economy for international trade, for interaction with other countries, and for the purpose of earning money to pay back loans? It's very seldom a restrictive thing of them doing something internally.

Dr. Friedman: I'm glad you made that point because the international trade aspect is critically important and one of the key problems I didn't have time to mention. Much of my time in the last year or so has been devoted to what we call our "commodity study." The governments of the world have asked us whether we can do something about this problem of the international trade with the less-developed countries. These are countries which need strong export positions to help finance imports. Yet, if you look at what constitutes their exports, you find that, in the less-developed world, 20 percent is petroleum which, of course, is very good. However, they depend mostly upon coffee, tea, rubber, tin, fats and oils, coconuts, oranges, and so forth. In order to diversify these economies, in order to give them more exports which are less vulnerable to price fluctuations, we try to strengthen their exports in addition to improving productive capacities. Of course, hopefully we try to harmonize the two.

Our problem here is that the developed world shows little interest in moving over and making room for any newcomer on the economic scene. As long as these countries want to produce coffee, the developed countries say that's great. If they want to produce more tea, fine. Of course, we won't reduce our taxes on the coffee and thereby increase coffee consumption because that's an important source of revenue. If the less-developed countries want to produce rubber, that's great. You want to produce rubber tires, fine, as long as you don't sell them to us. Of course, it just happens that the big markets of the world are in the developed countries. Of course, I am exaggerating, but the problem is there. You can't hope to develop a major export trade based upon greater sales to those other poor countries that are trying to diversify themselves. It is to the credit of some developed countries that they have recognized this problem and have made some adaptations of their trade policies with these less-developed countries. These things come too slowly.

Take another kind of export problem, you go to a country and say, "We're going to diversify your economy. What we find is that you'd be great in electronics. Why? Because you can get a few people from firms in the United States, Germany, or elsewhere, to set up an electronics parts plant so that they can have cheaper sources of supply. They can run it for you. It can be insulated from the rest of the economy. They'll produce these parts and you'll have a ready market." As an example, the industrialization of Korea is one of the brightest spots in the developing world today. Private investment has gone there, found local entrepreneurs, established plants, and has overcome this problem of market access. This is one of the reasons why we're very much in favor of private investment abroad.

DISCUSSION OF FRIEDMAN PAPER

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Let me start by mentioning something very familiar to all of us, and then going the other way, sort of looking from the inside out, to see how we can make connections with this distinguished speaker and the remarks he has made.

The first point I would like to dwell on just a little bit is the problem mentioned by Dr. Friedman; namely, that of goal-setting or performance criteria. Consider this equation for a moment:

$$J = \int_{t_o}^{t_f = 20 \text{ yrs}} U[C(x,u,t)]\, dt$$

The J (usually denoting performance criteria) is equal to an integral from initial time, t_o, to the terminal time t_f (maybe 20 years) of a function U.

Most control theorists will recognize this as a very general performance criteria. U stands for utility. The C in socio-economic jargon stands for consumption. As for the x and u--the x usually represents amounts of machines available--investment, buildings, and the like; these are state variables. The u is the control variable--the amount of savings you want to use, the amount of reinvestment you want to employ, the interest rate subject to Reserve Board control, and such things.

First of all, this problem of utility. Given a certain consumption bundle, which is a vector, how do you map that into a scalar function? This is something I think control theorists tend to ignore, saying, "Well, somebody has to do this." But it is far from a trivial job to say that at any given time you can have an instantaneous utility function. This requires very restrictive assumptions.

Secondly, to say that a planning horizon of 20 years involves "instantaneous" utility functions is adequate, is again a very, very restrictive assumption. Economists spend a lot of time trying to justify such a thing, and they have very strong opinions in this field as to why this kind of criterion is simply not applicable in the real world. In other words, the utility function should be interdependent over a period of time and not simply additive as represented by the integral.

Another complication is that very few people really believe that all the problems in the socio-economic area can be summarized by a scalar criteria function. Usually we are interested in a vector criterion function; and if once you admit the fact that you perhaps want to be interested in a vector criteria function, you immediately get into the realm of nonzero-sum games, or even differential games, which we know very little about. So the fact that the control theorist uses this as a start, puts the applicable part of the theory into a very, very restrictive class of economic and social problems.

There is considerable controversy as to how to get this kind of function. Dr. Friedman asked how we know this planning horizon is correct--this one of 20 years. What do you want left to the next generation after 20 years? These are problems completely untouched by control theorists; mathematical economists are just beginning to struggle with them.

This problem of goal-setting or defining performance criteria is a very difficult subject, even in a theoretical sense. Then, when you bring these political and cultural transformations, you really get into quite a mess, as Dr. Friedman very eloquently pointed out.

Next, assuming some criterion has been settled upon, you have the problem of evaluation. The evaluation of any project you attempt to accomplish is again a very comprehensive problem. I can only refer you to some references. People like Moynihan and Shelling at Harvard have written excellent papers on this problem of evaluation; that is, how do you know what you have done or what you have observed is useful to your objective? It is very hard to evaluate the success of a project. Let me throw in jargon here. I just learned an new "word," namely, PPBS for Program Planning Budgeting Systems, and I understand Commerce or the State Department people use this "word" quite a bit.

I would also like to mention some practical constraints in these socio-economic problems. First of all, there is far less money in a socio-economic area than, let's say, in the space or military area with which we are more familiar. Just to give you an example, the budget of the State Department is about $6 billion a year; that's less than one-tenth of the DOD budget. Furthermore, in the State Department, this $6 billion is really not subject to control of the Secretary of State as the one in the DOD. You have some other agencies, such as the Office of Economic Opportunity, and, for example, in the 1950's, the Marshall Plan. All these monies are not subject to the control of the Secretary of State. They are controlled by different agencies. So this $6 billion budget is actually divided among many agencies. The Secretary of State does not have the kind of planning that is available to the Secretary of Defense. Another example is the figure that Dr. Friedman mentioned this morning; that the World Bank is operating on something like $1 billion a year. With less money, obviously,you can do less things.

Another thing in the socio-economic area is that people in these areas are less able to withstand pressure from outside. All of us, the public in general, feel we know something about social phenomena and economic problems; and we are much more insistent on and impatient for results, as compared to the military and space area.

Take the Apollo program for example. Here is a $40 billion investment committed purely on faith, because at the time President Kennedy decided to go ahead with Apollo, nobody could say for certain that in a given 10 years we would be able to achieve this goal. Just imagine trying to carry out a similar problem in the socio-economic field. There would be hues and cries raised by all kinds of interested groups if you tried to commit $40 billion to undertake some sort of social project. People are less likely to be willing to wait for 10 years before they see some tangible results.

Also in the military and space fields, it seems to me that you are more able to operate in a totalitarian way. In other words, the connection between objective and method is fairly direct. For example, in the military area, if cost is no consideration, almost every military project can be justified as providing some kind of benefit to the security of the nation, and so forth.

In the socio-economic areas, this is far less certain. The private good enters into the questions more directly as the first-order effect rather than the second-order effect than in the military and space fields. Also in the military area or space areas, a very large project often is started through the decision of a very small number of people, as in the Apollo project. Again, in the socio-economic areas, this is much more difficult to do. In other words, you have the Congress and so forth with which to deal. Everybody feels they ought to have a say in carrying out any project of this type. So it seems to me,from the viewpoint of a person working in control theory looking out, I have a somewhat pessimistic view of our ability to operate in this arena and do some good. It is one thing to say after a few cocktails that we will or we can apply our control theory to solve the ills of the world. It's another thing really to be able to tackle some hard-nosed problems, to quantify these problems, and to put them into a mathematical equation and begin to operate upon them.

By this I don't mean that we shouldn't be working on mathematical economics or trying to solve urban problems, but I think there really exists a tremendous gap between what we are able to do in terms of control theory and real-world problems.

On the other hand, there are a few brighter aspects of this question which I will mention. First of all, it seems to me that the country as a whole is now beginning to turn its direction away from the military and space fields and beginning to address itself to more of these socio-economic problems that are plaguing us. One indication of this is seen when you look at the President's Science Advisory Committee. In the past, it has always been comprised of members of the Physics community. Just recently, I think, one member appointed to the President's Science Advisory Committee was a social scientist. That's one indication of the interest of the nation. And the National Science Foundation has recently been given a charter to sponsor research in the social science area, which we haven't been able to do before.

How can research in mathematics, economics, or control theory help solve these problems? I would like to give you a not-so-very-flattering analogy. In the Middle Ages, a lot of alchemists were trying to turn lead into gold. They never succeeded, but they created the science of chemistry. I feel a lot of research that's being carried on right now, although it is not going to solve any real-world problems in the immediate future, does create an awareness on the part of scientists and engineers of these socio-economic problems. It also forces us to think systematically and rationally about these problems.

Another possible area where a technologist may do some good is this. Quite a few of the problems, it seems to me, have a very strong technological component in the socio-economic area. I will give you two examples of past success stories, which show how technology, in some sense, solved a socio-economic problem. One is world-wide spread of poverty that was predicted by Marx in the 18th or 19th century. Because of technological advances, we were actually able to create very affluent capitalistic societies in Western Europe and in the United States without going through this social revolution predicted by Marx.

With technology we are able to fix sort of a basic social problem — at least temporarily. The idea of a "technological fix" was advanced by Dr. A.M. Weinberg.* Another example is world-wide war. The hydrogen bomb essentially reduced the problem of world-wide war to an irrational proposition. There is nobody in his right mind who would now think of starting a world war because of the availability of the hydrogen bomb. We have been enjoying peace for the last 25 years, although it is a very tenuous kind of peace. Neverthelss, I think if it weren't for the fact that the hydrogen bomb is available, we may not have enjoyed this peace at all.

Perhaps if we can make further technological advances to make even limited war irrational, I think we would have provided another kind of technological fix.

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* *Applied Science and Technological Progress:* Report by the National Academy of Sciences, U.S. Government Printing Office, June 1967.

For the other technological fix we can visualize in the future, I will quote some results studied by Dr. Weinberg of the Oak Ridge National Laboratory. The Apollo project cost $200 per person (for every man, woman, and child in the United States.) For that sum, last Christmas we saw on television the drama of the Apollo 8. He calculated that if we spent $400 per person in desalination projects around the world to convert sea water to pure water and simultaneously applied sophisticated agricultural techniques, we could feed an additional 60 million mouths per year. So, here is another technological fix we can use to alleviate at least the population problem for the moment. It is not a permanent solution, but it is a temporary fix. We can think of some better permanent solutions until a cultural-religious transformation has taken place that stops the population increase.

Another kind of technological fix that has been proposed is in traffic safety--how to make safer cars. You are not going to eliminate the problem of unsafe drivers, but if you can make the car safer, presumably this would help. It seems to me that we, as engineers and scientists, could address ourselves to technological solutions that temporarily fix the socio-economic problems.

FLOOR DISCUSSION

Dr. Harold Kusher: In a way, I don't find your analysis too dismaying because personally I would feel rather uncomfortable if the burden of saving the world lay on my shoulders as a control engineer. I am glad in a way that I can't really contribute to overthrowing anything that is very large. But somehow, if one looks at things from microscopic points of view, suppose a company or a country has five aircraft. Suppose they can make an analysis of the airports and markets and so forth and want to schedule aircraft landings and departures. There are various techniques that people might use to try to optimize the scheduling of these five aircraft. One might consider this as a control problem. Certainly people who do this sort of thing sometimes think of themselves as operations researchers; sometimes as controllers.

This kind of thing has to do with optimal allocation of a certain kind of resource on a somewhat lower level. It is not a question of changing the world population control and so forth. A hospital or city can analyze its inventory and optimize in some sense its ordering procedure to minimize storage costs and things of this sort and minimize the likelihood of running out. This might involve analysis of the rate at which certain types of drugs and other things are used. This is, in a certain sense, a social problem, and yet control is quite relevant.

There is another thing. I don't feel too dismayed by the limitations of scalar cost criteria because I think an engineer designing anything (not an economic system) usually takes scalar criteria very seriously. He would have to be out of his mind not to. I have the feeling that if optimum control techniques are ever to become very useful in any systematic way in economic problems, one would apply them to a number of criteria and see what happens. If there is a great difference in sensitivity when varying criteria are applied, then new judgments and new types of ideas, decisions, and criteria come in, and you would choose one.

But the idea is that some things are important. You might want to minimize the number of people involved in a project, and so forth. It seems that it would be interesting, in any case, to know what kinds of procedures would do this. At the same time, you would want to know what the drawbacks of a given procedure are. But certainly if one uses Arder's notion of non-inferior controls for vector criteria and so on, this might eliminate nonsensical criteria, but it still leaves you with a lot of choice. It seems one of the only ways to evaluate these choices is by using scalar criteria.

Until a few years ago, a great deal of control theory was based on second-order, linear, constant-coefficient systems which very few engineers really felt represented anything that they really had to deal with. Somehow they felt they got some insight from this one-input, one-output, second-order system. I think it is probably something analogous to this scalar criteria.

Professor Ho: At the level you are talking about, I agree with you. In fact, I said these researchers should be supported, but we shouldn't delude ourselves into thinking that the theorems we prove and techniques we develop are going to solve the socio-economic problems that we are addressing ourselves to right now.

Dr. Kahne: I think one question we should ask ourselves is: What basic philosophical approaches do we have as control engineers that other people don't have? As an example, something we take for granted all the time is that there exists something called feedback, and that this is very useful. But if you go into several of the social areas and try to find out – without using the word – whether or not feedback is a well-known and well-used concept, I think you will find out it normally isn't.

One place where control engineers can contribute is in approaching problems using their own philosophical strengths, and one of them is feedback, and there are probably others if you think about it. But one of the questions is whether a new group of people – if you assume the control engineers to be a new group of people – should analyze their own basic philosophical approaches to problems and compare them with the basic philosophical approaches of people in the field a long time. Maybe that is one way to get at the problem.

Dr. Robert Gustafson: Maybe a philosophical approach that could be used here is the notion of simulation. If you can create a model of a particular situation and use that as something to experiment on, if you have a simulation of an economy, a simulation of an investment situation, you can essentially get a look into it further by running experiments on that simulation model and trying various types of taxation policy in the case of a country. In the case of a hospital ordering system, you can try various schemes relatively inexpensively on a simulation model. And here you don't really have to worry about vector-valued performance functions or optimal control. You can almost fly by the seat of your pants as far as designing a system which is better than the system that you have now.

Professor Ho: Let me make a point on this. If you are talking about small-scale simulation, microscopic phenomenon, yes, I would agree with you. If you are talking about real large-scale simulation, I think if you really start trying to do something like the input-output analysis and simulation of national economies, this runs into literally millions of dollars for computer time. It is not a trivial matter. Academic simulations, okay; but a simulation on real-world problems, I think, is far from the type of simulating we tend to work with in laboratories and so forth.

Dr. Kushner: I would like to ask Dr. Friedman a question about an economic analogy to the Rand Corporation-type of military gaming. As I understand this, suppose one has a situation where one is interested in tactical air support for ground troops. Say, both the Air Force and the Army are competing to run and operate the planes. There are lots of problems, logistics, and other things as well; coordination problems between the air and ground commanders are involved in this. Apparently the problem is very complicated and no one can figure out what is going to happen beforehand. One of the ways in which things like this apparently have been handled is to get various teams. For instance, they get the enemy and they get you in one room and in some other room there is another team. One team is the Air Force, plus ground troops, and the other team is the Army, plus ground troups, and they sort of act out things. It is very clever to play the enemy side and see what sort of situations might happen.

Suppose you run out of planes, how do you get new ones? There are constraints, numbers of planes, problems of logistics, the time it takes to get parts from the United States or Okinawa, wherever they might be supported. In any case the idea is somehow to dispense with a certain amount of mathematical formalism. Use it primarily in only small-scale things, like linear programming to optimize flight paths or something of this sort, but you wouldn't use game theory to solve the war problem.

I was wondering whether such things are used in economics. One might imagine one trying to develop a plan of investment in a country and not know what happened. You can sort of simulate this in a way. On one side, you might have guys from the country making good decisions, on one hand, and bad decisions on the other. But one of the things I think that has come out of these military things is that you can't quite predict how clever an enemy will be. On the other hand, in the past, successful generals have tried to map out things. They look at one side of the board and what they would do and say what the enemy will do. They sort of know in their own minds what their own disposition is. And it is very difficult to play both sides. It is difficult to play yourself in chess very honestly. I have never been able to.

So the idea is really to have a mock battle under realistic conditions to see what kinds of things might turn up. I was wondering whether anything like this has been conceived of or whether it would be useful to do anything like this in economic planning.

Dr. Friedman: Of course, game theory has been used in economics, but we will say in terms of development of economics. It is not used very much to my knowledge. We have talked about it in the World Bank but have never used it. But we can easily imagine many situations where it might be interesting to use it.

One situation is one I alluded to before, a game in which you try to talk to a country providing, say, $1 billion in foreign aid a year for less developed countries, and ask them whether they would rather do it between or by changing their foreign trade policy so the less-developed countries can earn the $1 billion more through imports, or would they rather do it through its budget by providing it out of budgetary funds. There's a problem. You really don't know which one they would rather do. The adversary here is presumably some public attitude or an attitude of legislative bodies because you might have competing interests between commercial interests, on the one hand, who are very concerned about trade, against financial interests, on the other, who are concerned about the control of budgets and what this means to taxation policies.

It has been suggested this might be worthwhile doing, but we haven't done very much on it really, except to talk about it. We have wondered whether or not it would be worthwhile. Partly it is a question of scarce resources in terms of time and people. We don't have enough experience with any of these things to know what the payoff will be at the end.

I will give you a simple illustration of this problem. The Bank never had a procedure for estimating what the benefits were after the completion of a project. You have made, of course, cost-benefit analyses in advance of the project and you have very carefully calculated financial benefits. These didn't prove to be good and high enough, so you add economic benefits (which is great for the economist because he can add anything he wants.) Then, of course, the relationship becomes good enough to justify the proposal. But no one had set up a system of built-in data collection, so that when the project was all through and operating for a few years, you knew if you really did get the benefits you thought you would get out of it.

In all the history of the Bank, the first post-analysis was done on Iran's highway system to which, of course, exactly what you talked about, happened, the unexpected things like feedback and so forth. What happened was that the prior estimates were just not bad quantitatively; they didn't have the same components. You got a total benefit out of the project which justified the original project, but it wasn't for what you thought it was going to be. You got benefits you hadn't anticipated. By and large, looking back at it, you were "happy" that you did the project but not for the reason you thought you were going to be happy, rather because of the unexpected impacts of the investment on various aspects of economic life of the country.

One of the things we are trying to do is to develop within the project presentation and evaluation, the kinds of data that would enable you to evaluate the benefits after the events. The reason I cite you this is that it took about three years of discussion to decide to do this. People are so busy and uncertain as to whether or not this would have been worthwile doing that, although people talk about how nice it would be, they don't really do it. And there is a lot of feeling that with game theory we could learn a lot because we could imagine a number of situations. Our greatest imagined adversary is just Nature: For example, the presence of typhoons in the Phillipines and what they do year after year to knock out crops – and what this means for the economy.

It would be interesting to play games using Nature as your adversary making different assumptions as to how often it is going to come and what you will do about it, depending on where it strikes and whether it knocked out the sugar crops or apple tree crop or cocoa crop. This is the kind of thing we have been thinking about.

Dr. Vernon Foster: I would like to ask about the input-output economics and some of the work done until about 5 years ago. Paul Chinery has been doing a lot of this. I think they had done 40 projects on underdeveloped countries. What has happened to that? Could anybody speak about that?

Professor Ho: All I know is he is now at Harvard starting a very big simulation project. I don't know anything more.

Dr. Foster: Hasn't it been carried forward at all?

Professor Ho: As far as I know, he has a lot of people working in this area of quantitative economics, studying growth theory and so forth. Right now we are talking about the vector X; with maybe, three or four variables. Nowhere near the hundreds of variables we would like.

Dr. Foster: It is very complicated, but it looks to me like it would give us a kind of picture. Maybe not. Would you agree with that?

Dr. Friedman: We have begun to pick up some of this work in the World Bank, particularly where the universities are running dry of money. Sometimes they have been asking us whether we would be interested in cooperating on the continuous research; we are open to suggestions on this.

But the problem still is that the models being used are really much too oversimplified for policy-making. They were thought in the beginning not to be good enough for policy-making, and recognized as such. In the end, they *were* used for policy-making.

Dr. Foster: Didn't you have anything better?

Dr. Friedman: People couldn't resist the temptation to use them for policy-making, and this led to false expectations as to really what was going to happen from certain investment decisions. People have been burned by this. People have become very cautious.

One of the things, for example, that has come up on one of those models you are talking about is a simple problem like this: you build into a model an input of, say, 5 percent of the gross domestic product, coming in as an increment through the import surplus. This has an obvious implication that the U.S. aid program is going to provide the money for, we will say, 60 percent of that input. Then, Congress cuts the budget in half. What do you do? This is exactly what has happened in one country right now that is struggling with this problem. The country was encouraged to go ahead with the investment program based on this model, but the model had a prior assumption which was the willingness of the donor country to provide resources which ultimately it didn't deliver.

What had not been worked out was what would happen if the external resources were cut off. There wasn't an alternative program. One of the problems we are struggling with right now is whether we should fund this program, because of the disruptive losses involved. This is the kind of thing that is involved in the input-output model. We are not merely trying to understand the inputs and outputs as of the year 1960 or 1965. That would be one thing. What we are really trying to do is project it forward and put in inputs which we are quite uncertain about. In many critical areas the input is not under the control of domestic government policy. It is under the control either of foreign trade policy or foreign financial policy. These are the kinds of constraints you operate with when you use these kinds of models — when you project them forward in time. And the more you project forward in time, the more uncertain these various elements become.

Professor Robert Cannon: I want to say explicitly what I think I am hearing here, because I think it might be kind of useful in a structural way. The most elaborate, largest capacity computer still around is a person; and one of the ways to simulate an economic model is to train a bunch of people to think like the situation. This is the judgment thing that you brought up at lunchtime. The way you program this kind of a model and, in fact, the way you develop the model in this kind of computer is to construct the model from a group of people who have trained themselves by being on the spot, by living with people, by drinking and spending evenings with economic advisors in other countries – this sort of thing – until they have adopted a very complicated model that you could never write down on paper.

I guess the point I am trying to make is that these two kinds of simulation: (1) the machine simulation wherein you must be able to write everything out explicitly; and (2) the teams-of-people kind of simulation – these two approaches have a great deal to learn from each other.

The teams-of-people kind of simulation can learn how to be more structured in what they are doing if they learn to think in terms of the models you would some day like to write out. The people who are making machine simulations have a great deal to learn by watching how the models seem to evolve through the people who make our decisions, though perhaps not in a highly structured way. The way they think about the problem is important. It may be that we are trying to work these two problems out in a complementary way. These two kinds of simulations could evolve into something very much better than either of them.

Dr. Robert Price: I would like to address the discussion both to Dr. Friedman and Professor Ho – the thought being that two heads are better than one.

As I understand it, we owe quite a bit to the Russians for the genesis of modern control theory, and I would presume there is an organization in the Eastern Block somewhat analogous to the World Bank. Maybe there is a meeting of these two groups on the other side of the Curtain. My specific question is, Are we able to communicate with the "World Bank of Moscow" and learn about what their experiences are in resource allocation and maybe share our experiences with them? This is, of course, at the people level and not at the machine level.

Dr. Friedman: The simple answer is "no." I am not sure there is really an analogous thing in the development field. There is an analogous thing in the monetary field, which is a sort of intercentral banking arrangement, but I don't know of any in the development field. We have very little communication with them.

It is very interesting to find, however, that we have been hearing more and more from the European countries. They are very eager to get our data, both on countries and on what we consider to be the comparative data to use in a systematic fashion. I think what we are trying to do is bring these two things together. This may not be a game theory but rather an attempt to get one answer from the persons who work in a structured way and an answer to the same question from people working in this more inarticulated way, and then compare the two answers. Then, when the answers are different, to confront them with each other and say, "Really, why did you differ? What do you think the credit-worth of Turkey is?"

The unstructured people are the most pessimistic ones because they are always concerned and sometimes overwhelmed by short-run phenomena. They are talking to the world as it is; and the world as it is, is often a very uncertain place. Whereas the structured person has a way of cutting through the short-run and saying you are really going to live beyond the present administration and that maybe you will be in a different situation and these are the different ways it might happen.

Then, you put it up to the unstructured ones and say "Is this real or unreal? Could we help make it happen this way?" I find this sort of dialogue between the two very useful. Someone has gotten wind of all this in the Eastern European countries, and we find quite a number of requests for our material.

By and large, we have a policy that unless it is objected to by the country concerned, we do make available material to them. We have been developing a very comprehensive data bank based largely on national income analyses on internationally comparable basis. This is the kind of data we will make available to them, but we find it feeds on itself. The more we give them the more they want – we give them one memorandum and get a request for 20 more. They obviously feel a great need for more information of the kind we have been putting together. Whether it is just to compare with something they themselves know, as a kind of check, or whether it is new information for them, I honestly don't know.

CONTROL TECHNOLOGY APPLIED TO PRODUCTION PROBLEMS

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"Production" is a general word. In my industry it means getting oil out of the ground, while in the chemical industry it means making chemicals. I assume it means turning out steel ingots in the steel industry. No one in the world is familiar with all phases of production control in the U.S.A.; therefore, I am going to discuss only a few of the problems in the oil and chemical industries associated with control and automation.

I shall be emphasizing the need for profitable installations; by this I mean control systems that will pay off in 3 to 5 years or less. This payoff is essential if we hope to have significant gains in automation in these industries.

When I was asked to speak on this topic, I initiated some library work to really find out things I thought you might not know. After one weekend in the library, I decided this was a losing proposition. I decided you didn't want to hear what was in the literature; you wanted to hear what people in industry have had to say about control problems. Now, I'm not an instrument engineer, so I'm not going to tell you how to solve your detailed problems; however, I do give you a hearty invitation to join me and my colleagues in the area of process design and to help us automate the big plants that America will be building this year, next year, and in the future.

EXTENT OF COMPUTER CONTROL IN INDUSTRY

At the present time there are from 2800 to 3000 control computer installations worldwide. The rate of new installations is approximately 20 per week. At this rate, some 5000 process control computers will be in existence by 1970. So I think one can safely predict that process computer control is here to stay.

Control computer installations in the U.S. make up some 60 percent of the worldwide total. The remainder is spread amongst the developed Western nations plus Japan. The communist countries do not appear to be too active, but it is difficult to assess the situation there.

Petroleum and chemicals still lead in the number of installations by industry. The trend of applications in these plants, as shown by Ostfeld*, illustrates about the same distribution in 1967 as in prior years. The primary areas of application are: (1) pilot plant studies, simulations, etc.; (2) refinery data logging and/or control; (3) chromatograph and laboratory analysis; (4) blending, producing, and drilling; and (5) general chemical processes. New computer installations for control of pipelines in the U.S.A. and general chemical applications in Europe dropped significantly in 1967. Litigations between the U.S. Government and pipeline companies, plus the restriction of U.S. investment in Europe, are felt to be the reasons for these declines. American companies have been primarily responsible for adding computer control in Europe rather than their European competitors.

Electric power plant control computers are proliferating rapidly; so are installations in the metal industry. Cement and paper plant applications are growing steadily after feasibility was established by pioneering applications. A so-called miscellaneous area accounts for a large number of installations. Some of these are not rated as "control computers" in the standard sense. However, all have some sort of an overall or gross function as contrasted to pure office-type data processing. In this category such diverse applications as newspaper typesetting, freight train makeup, and TV program switching control are found.

Fortunately for the user, the manufacture and selling of process control computer hardware is, and always has been very competitive. There are some 16 major vendors, plus others, trying to get into the field. No single one of the major hardware manufacturers has more than about 50 percent of the announced Free World business. This number decreases to a figure of about 1.5 percent for the smallest manufacturer. Such competition has resulted in reasonable and realistic pricing, with a break for the customer.

Automation in the oil and gas fields, pipelines, and related areas is economical and several systems are now operating. A typical installation may include from 500 to 1000 wells under supervisory computer control. Payoffs are achieved through lower tankage requirements, reduced manpower, better field data, and printed production and controller reports.

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* Ostfeld, D.M., "DDC--Where Do We Go From Here?", Paper No. CC-68-86, presented at the National Petroleum Refiners Association Meeting, November 6-8, 1968, Philadelphia, Pa.

In the petroleum refining area, fluid catalytic cracking, crude distillation, and alkylation processes are receiving the most attention. Rather detailed material has been published on fluid catalytic cracking control using digital control techniques. In fact, some companies now have almost seven years of operating experience with digital computer control of their fluid catalytic crackers. It is safe to say that no new fluid unit of substantial size would be built today without at least a careful evaluation of digital control. The initial objective of catalytic cracker digital control has been optimization rather than control enforcement per se.

In the chemical and petrochemical field we have an industry where a wide gap exists between levels of control sophistication. Many chemical plants, particularly those of the small-pots-and-pans type, still use locally mounted pneumatic, open-loop controls developed in the 1930's. In contrast, some chemical complexes employ the most advanced concepts of multilevel digital computer control, starting with direct digital control (DDC) at the process itself. Ammonia and ethylene processes are the two largest areas of interest; here, some 14 and 19 computer-controlled installations, respectively, were in existence in 1967. Again, it is the exception when plants of this type are not at least evaluated for computer control in the design stage.

The polymerization of butadiene and styrene to produce synthetic rubber latex is now controlled by digital computers in a number of plants. This application is especially significant because the process has long been one of the more difficult ones to control — especially from the standpoint of quality control.

In the paper industry, digesters, stock preparation, paper mills, and head-box control are centers of computer application activity. Although hampered by early failures, a number of existing computer control applications have been carefully evaluated and found economically justified. It appears that the so-called "agony of justification" was especially acute in the paper industry.

Rock-blending operations and kiln control have been successfully controlled by computers in the cement industry. This industry is to be commended. For years cement had been made using rudimentary control methods. In early 1960 several operators studied digital techniques closely. Several firms have since reported impressive production, quality, and consequent financial gains through the use of advanced digital control techniques.

For a number of years the steel industry searched for the best place to apply computer control in the manufacture of steel. Basic-oxygen furnaces received attention first, and several successful applications now exist. However, the area receiving the major effort now is automated hot-strip-mill operation as well as automated continuous steel casting.

The power industry rates highest in actual penetration by digital control. It is estimated that the power industry is more than 65 percent computer-controlled, nation-wide, and is automated on all new units above 600 megawatts. Boiler-turbine-generator startup, operation, and shutdown are the specific areas of application. Analysis of power distribution systems and their control is also receiving much attention at present.

I understand that computer control is penetrating the area of "discrete manufacturing"; that of TV sets, transistors, and even computer parts. I thought it ironical that our larger computer manufacturers had not put their production activities under computer control much earlier.

Returning to the petroleum and petrochemical field, the following percentages illustrate the degree of computer control within each segment of the field in the United States:

Pilot Plants	Refineries	Labs	Blending and Others	General Chemicals
10%	25%	10%	25%	32 - 33%

The above data cannot be used to extrapolate for the near-term future because two important trends are emerging that will alter the picture: (1) the hierarchy concept, involving total plant computerization, is not so popular in the chemical and related industries at the present time as single-machine computer application and computer control of certain units within the plant, and (2) machines presently on order for the petroleum and chemical industries are destined mainly for analytical control, inventory control, and pilot-plant supervision, with less emphasis on process control *per se.*

I quote from Ostfeld's paper:

> *"Process control has now reached a plateau, especially in D.D.C [direct digital control], where companies in evaluating their present position from their past experience, reliability problems, application justification, and monetary investment are hesitant to commit themselves to further computer control. Much of the hesitancy to install process control computers is caused by the problems encountered in the software and hardware areas during the initial stages of third-generation computers two years ago, which are now solved for the most part. This hesitancy has been further stimulated by the past history of edict buying of computers for experimentation with little regard to potential profitability, coupled with gross underestimations, resulting in little profit being subsequently realized to justify the actual expenditure.*
>
> *"The next few years will be critical in shaping the trends of process control applications and in guaranteeing positive results from these applications to stabilize their utilization and insure their value. The keys to this shaping lie in future developments and utilization of four major areas:*
>
> 1. *Adequate computer justification and scope description;*
> 2. *Further emphasis in software standardization and new developments in control application technology;*
> 3. *Additional developments in hardware reliability earlier in the project life and improved information display systems;*
> 4. *The role of user and vendor in system responsibility."*

I am more optimistic, along with Dr. Williams, who will present this view later.

JUSTIFYING COMPUTER CONTROL

In the area of project planning, computer justification, and scope delineation, we can discuss the need for good engineering practices. Some of the larger manufacturing companies have formal groups which design their process-control systems. These people are full-time, permanent career men whose primary interest lies in the application of control to the process industries. These men would normally work as part of an engineering center where they would handle actual installation and operation of control computers; including evaluation, specification writing, systems analysis, programming, instrument modifications, and debugging.

On the other hand, many companies do not believe in this approach or else cannot afford it. They prefer to use a task force of key men from research and development, from manufacturing, and from mathematical and computer service groups as an adjunct to the design engineering groups. When the control unit operates successfully, the task force is disbanded and the men return to their permanent jobs. Another approach is to use a team of outside consultants or an engineering contractor qualified to do this highly sophisticated work. There are several firms now specializing in this type of work. None of the three methods above can be considered the best approach, but we believe the method selected is a function of the user "personality." By this, we mean the staffing policy history, the level of technology in the company, its attitude toward know-how, and the degree of secrecy desired by the company. The important thing is to match properly the approach to the inherent corporate characteristics.

With respect to the justification of the project, I quote again from Ostfeld:

> *"The evaluation phases are the least understood and most ill-used portions of the entire project. The two areas of extreme difficulty are benefits and programming costs. Within the limits of reasonable study cost, it is impossible to completely predict what the computer will gain for the unit; i.e., it is impossible to completely determine how much better the computer will perform than the unit operators and/or added equipment toward reaching the theoretical optimum capabilities of the unit. As with a market study, the evaluation studies are used to diminish the risk involved in committing the money to the project by lowering the probability of error in the estimate of computer gains and narrowing their confidence limits."*

> *"Similarly, the programming costs cannot be completely determined until the programming is finished. Until sufficient corporation experience has been developed to allow for factored costs (for example, the labor factors in plant construction) in the estimate, the software and the hardware are dependent for estimating purposes upon the experience of the individuals considering and scoping the project."*

Since all process companies are in business to make money, economics are of prime importance here. You cannot install any unit just because it does a nice engineering job, nor a control because it keeps the unit under good control; it must pay off economically.

In general, any new computer-control project will be given a preliminary evaluation. At this stage, you must know the type of unit or units involved and if, indeed, they are making money and how much. In fact, we were told recently by one of the well-known instrument companies that our ethylene plant was the most likely target for a computer installation rather than one of our refinery units because of cash flows involved in this unit. At this moment I am not ready to accept this and will speak more about this later. Based on the cash flow of the unit or the plant and then the cost of the equipment, the incentives to install a computer will vary depending upon whether the unit is production-limited or market-limited, on the size of the units involved, and the philosophy of the method of control. You might say that you are trying to set the scope of the project. After you have assumed reasonable values for the benefits, then you can study the economics of the various configurations and compare them with each other.

The investment in the computer must be paid off by improving the cash flow in the plant. In the market-limited case, the improvements will be in product yield and quality with lowered raw material cost. For the production-limited case, the improvements take the form of increased capacity of the unit. Usually, the latter is the reason you put a unit under computer control. Other costs may enter here, such as utility cost, plant maintenance cost, and the ability to use different feedstocks. However, these are usually of small benefit compared with the increase in production, although they all influence plant operation.

Some of the details that should be checked as to whether or not supervisory control should be added to a plant are:

1. The interaction of the individual units;

2. The types of units and their complexities; the number of loops that must be controlled in the units are of prime importance here;

3. The ease of control and what method of control works best.

One of the main uses for a process control computer is the flexibility you gain during the initial plant startup. When you are talking about saving $10's of thousands each day, this can be a real economic incentive. Presumably, with the better information that is generated and recorded, you can better "de-bottleneck" the plant and make process improvements. There is another side to this question; the engineer may be flooded with data and therefore can become more-than-slightly confused.

Other justifications for the control computer can be data acquisition for management purposes, material balances, yields, efficiencies, inventory control, and similar data. The computer may also be programmed for plant optimization. The ability to make decisions based on the acquisition of information at the correct time may favorably influence the decision to put in computer control.

SOFTWARE PROBLEMS

Now, let's briefly mention "software" and the problems connected with it. Standardization of software has been proposed and there is a meeting scheduled at Purdue next week sponsored by my colleague's [T. Williams] department. He will tell you more about this meeting.

Vendors have begun to understand that they cannot build a special machine for each situation, at least at the computer level, and still make money. They are very vocal in wanting standard software. I am sure it is going to be necessary to create some standardization here; it will probably be analogous to the language problem during the early days of computers. We may end up with two or three software systems.

I will leave this area for Dr. Williams to discuss in depth.

HARDWARE PROBLEMS

Input-output equipment needs improving, especially with respect to reliability. I expect the competition that I mentioned above will help in these areas. The man-machine interface must be improved. To effect real improvements here we must be aware of the improvements we need, and I expect this will evolve as our technology improves. Dr. Williams will say something on this later.

One of my instrument engineers told me that we have relied for many, many years on the "four horsemen" -- flow, temperature, pressure, and level control -- but that today a fifth man has been added to the backfield, a chemical analyzer. We now have on-line analyzers, mostly gas chromatographs, which do a fine job; however, they are essentially batch-type instruments and this creates a problem. The chromatographs take time to give us a sample analysis. On some processes you may need a complete bank of gas chromatographs to do the work. For instance, we measure 22 components in catalytic reforming; and, in order to do this, we may need several batch analyzers, one following another in series. This series may be as sensitive and crucial as the process itself. We may be more concerned about the dynamics of the measuring devices than we are in the dynamics of the processes. This is the tail wagging the dog.

One very important aspect of the problem is the sampling. When you have the analyzer--even when it is working properly--you always wonder if you are getting a satisfactory sample. Of course, on large process lines, getting a composite sample is one of the problems. If you are dealing with solids, semi-solids, or liquids, you again have difficulty in getting a sample which is representative of the whole. However, this is only part of the problem in getting some kind of reliable automated device to give you a correct sample. Several of the instrument companies today claim they can help you design a good sampling device. Generally speaking, all they will do for you is give you an engineering drawing; you build your own device and hope that it works. And there is very little to help you determine whether this device is working properly or not.

In addition to the sampling problem, there is uncertainty in the accuracy of gas chromatographs, even those for which you pay a considerable sum of money. For instance, on an ethylene plant, you will find that you can analyze all of the components, except hydrogen, using the chromatograph. Yet, to do a good job of controlling an ethylene cracking furnace, you must know the amount of hydrogen in the cracked gas.

I have discussed computer control and some of the problems associated with it, especially economics and justifying the installation of a computer. The gains made, particularly with digital computer control, in the last 10 years are remarkable. The other side of the story, however, must be told. Some installations have been installed which were not worthwhile either in terms of technological advancement or economic payout. Fanning* reports, "There is nothing at all automatic or assured regarding success of an installation. In fact, it is very easy to install a digital control computer and get essentially nothing out of it." My own company put a control computer on a new process early in this decade. The process was fresh from the pilot plant and involved some slurry and solids handling. Needless to say, the computer did not stay in the plant very long. The process just wasn't ready for it.

OUTLOOK FOR THE FUTURE OF COMPUTER CONTROL

This leads me into a related area. The productive equipment and capital investment of U.S. industry is estimated to be about $1 trillion. Most of this equipment is not automated and represents a tremendous challenge to men in this field. This assumes there is a real payoff for automation, and I don't believe we would be here if we didn't think so. What can we do with this equipment? What is an economical way of dealing with this problem? Can we use small computers for controlling each of the particular units? For example, a special small computer could be used on each distillation tower, batch reactor, separator, furnace, or other piece of process equipment. These computers could be applied on the individual units and thus furnish the first level of control. When the next level of control is desired; i.e., when you hook several units together, you could use a small general-purpose computer. Finally, the entire plant could be controlled with a supervisory computer. Gentlemen, can this work? Is this feasible? Is it economical? Or do we wait until we can build a new plant and use a system approach only on the new plant? If the systems approach is necessary, I believe it will take at least two generations to get the productive equipment of America and Europe under supervisory control. In the U.S. we spend about $70 billion each year for new equipment; we may *not* have enough manpower to re-do the old along with the new. I believe we must first find a way to apply small computers to existing individual units; then, hook several together, and, finally, put the whole complex under supervisory control. Again, perhaps direct digital control (D.D.C.) is the answer, but in small doses since they can be sold to management much easier than a complete D.D.C. system on an entire complex.

Change, and the acceleration of change, is very rapid in many areas, particularly in the field we are discussing. We will be compelled to do something quite fast in this area for another reason. Just a moment ago I supposed that we could use a small computer on existing units, then tie them together for supervisory control; in particular, I wanted to know if this is economical. Now, I'd like to go off on another tack – one that has no direct payoff but yet may be as compelling as a one-year payoff. It is in the psychological area. Our society today is affluent and rapidly becoming more affluent. Because of this, we have some drones in our society and will undoubtedly have more if the present welfare situation continues. All of us have been responsible for some of this by our automation of some of the production facilities in America.

Today we have more workers in the service areas of our economy than in the production area, yet we are enjoying constantly rising standards of living. This ratio of service-to-production workers is rising rapidly, due in part to automation, since you can automate production easier than services. All of you are also aware of shortages of people in all lines of work, especially in those jobs

* Fanning, R.J., "A Decade of Digital Computer Control," presented at Louisiana State University Workshop on Digital Process Control in 1967.

that are dirty, cold, and socially unacceptable. As our economy produces more goods through automation, fewer workers will be required and some device, such as the guaranteed annual income, will give people money to buy the goods produced by the economy. This will remove the economic incentive for working, and industry will be forced to automate and work out control systems for those jobs that are lowest in the eyes of society. There will be no psychological reason for a man to work, for example, as a rag picker, garbage collector, janitor, or as a machine operator under adverse conditions, such as exist on the North Slope in Alaska, with temperatures as low as -80°F, or at the site of the Athasbaca tar sands, where temperatures of -65°F may prevail.

Will it become necessary to automate some machines because men will not work in the wilderness or under other adverse conditions, particularly when they can draw welfare payments in the big cities? The incentives for automating coal mining machinery are great because safety is an important consideration here, and I suspect this will force remote control of these machines very quickly. In any event, I am convinced that the rate-of-change of technology in these areas will be very high. An attempt should be made to quantitize this rate of change so that we can prepare for these future needs. We do a fine job of prediction in the economics area with our Gross National Product and other publicized data; perhaps this will come in automation as this field becomes larger and more people work in it. Needless to say, the shortage of good people probably limits our growth rate in automation and technology in general.

SOME COMPLEXITIES INVOLVED IN COMPUTER CONTROL OF CHEMICAL PROCESSES

Training and our knowledge of fundamentals are more critical than one might think in chemical process plant design, even where the reactions involved are simple and supposedly well-known. Back in the 1920's the physical chemist thought he knew the mechanisms of the reaction of hydrogen and bromine that produces hydrogen bromide. It is written up in the textbooks as a classical illustration of taking experimental data and deducing the mechanism of the reaction from the data. Within the last five years, this mechanism has been challenged and another "correct" mechanism has been postulated for this simple reaction. We, in the chemical and related industries, do not have many basic reaction mechanisms that we can rely upon and use without reservation. Because of this, we cannot design, *a priori* the control scheme for a simple reaction, let alone the complicated ones we have in a fluid catalytic cracker. Another part of our problem stems from not having full knowledge of all of the components in our feedstocks to our refineries. In a petrochemical plant you usually deal with well-known basic materials and reactions; e.g., benzene is produced from toluene. But in the case of refineries, we must deal with boiling-point ranges, true-boiling-point curves, ASTM distillations, and other empirical methods to handle the multitude of components present in the raw feedstock and intermediate streams. Frankly, we need to know more before we can design a control system from start. Now, after the unit is running, we can study it and deduce its behavior in terms of feedstocks and products, but the design is then fixed.

The last areas I'd like to speak to you about are reliability and safety. Of course, we who are involved in designing and building plants try to see that they are easy to start up, easy to maintain, and as reliable and safe as we can make them. The strong penetration of our industry by automation has made our design and operation decisions much more complicated and complex. Control engineers have given us another set of dimensions for our design parameters. I will review this situation.

In 1938 the process and plant designer was faced with only a couple of control choices. He could mount his large-case pneumatic instruments either locally or in a central control room. Now just 30 years later, here are his alternatives, starting with the simple and proceeding to the complex:

1. Pneumatic analog;
2. Electronics analog;
3. Pneumatic or electronic analog, plus data logging;
4. Supervisory digital control (SDC), on-line, with an analog system;
5. Supervisory digital control, off-line, with an analog system;
6. Direct digital control (D.D.C.), with various backup levels;
7. D.D.C./S.D.C. cascade for reliability;
8. Multilevel computers: D.D.C.-S.D.C.-corporate computer;
9. Permutations and combinations of the above, plus time-sharing of computers for engineering calculations, analytical supervision, data processing, etc.; and
10. "Hybrid" combinations of the special circuits using solid-state components and integrated circuits, plus general-purpose computers.

This list emphasizes the bewildering array of control instruments facing the design and instrument engineer, the technical manager, and corporate management. See Figure 1, for example, and note the complex array of controls and instruments. Because of this variety, we expect many different approaches from the equipment manufacturers and the theorists.

In all situations we must have reliability and safety. All of you are familiar with Murphy's Law: "If it can happen, it will happen, and furthermore the worst situation will develop." In the large plants we are building today there is too much at stake to allow the failure of a control system to pull the plant down. As I mentioned before, there are literally tens of thousands of dollars hanging on each day's operation — no room for error or failure. And plants are going to get bigger. Ammonia, ethylene, and fluid catalytic crackers are good examples. Let's look at ammonia. Ammonia was first produced commercially about 1913; about 20 years later we were making it in plants with capacities of 20 tons/day. In 1958, 300 tons/day was considered a large plant capacity. And in 1965, my company built one of the first 1000-tons/day units. Today you see 1500-tons/day units in operation with possibilities of 2000 to 3000 tons/day in the near future. The same is true of ethylene with 1,000,000,000 lb/year plants now on stream, with bigger plants a distinct possibility.

Our design engineers, in their efforts to provide the most economical unit, have built waste-heat boilers and have tied in the utilities with the rest of the unit to a high degree. This makes a unit that produces a low-cost product, but it is hard to start up and the waste-steam system is as critical as the rest of the plant. Reliability is the key word here.

Figure 1 - Complex array of controls and instruments is shown in Control Center at the Standard Oil Company in Toledo, Ohio

Today I've tried to stress the economics that must be met in the computer-control area before it will be used throughout the industry. I've mentioned the addition of analyzers to the old "four horsemen": pressure, flow, temperature, and level controls. We need better analyzers that operate continuously with a minimum of problems. We need small computers for individual units at the first level of control, we need to tie them together at the multi-unit level with a small inexpensive computer and, finally, at the top with a supervisory control system. I have talked some about fundamentals and our need for knowledge in our own field. And last, I have talked about large plants operating under adverse conditions where we stress reliability and safety for the whole unit.

I'd like to acknowledge several persons who helped in the preparation of this material. My special thanks to T.J. Williams, Purdue University; R.J. Fanning, Ethyl Corporation; and David Ostfeld, Fluor Corporation. The cooperation and help of members of various departments in Continental Oil Company is also appreciated.

DISCUSSION OF FOSTER PAPER

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* * * * *

Two major areas of endeavor in computer control should be brought to the attention of the OCTA Symposium attendees. These are: (1) the standardization of process control computer programs or software, and (2) the possible future development of systems hardware.

STANDARIZED SOFTWARE – A HOPED-FOR SOLUTION TO A MAJOR PERSONNEL PROBLEM

As stated earlier by Mr. Foster, most major hardware problems prevalent with the early process-control computer systems have now either been solved or the paths to their solution are clear. These problems have been replaced, however, by a set of equally difficult ones concerned with the system programming or software.

In our early applications, we consistently underestimated the size and complexity of the programs required to effect a successful control system. Also, these early computers lacked the programming aids now available with most manufacturers' equipments. As a result, large programs had to be squeezed into too-small memories by a programming staff which was itself too small. As a consequence, the final installations of the early machines were invariably late and required a very long and frustrating checkout period.

While programming aids, such as compilers and special process-control languages, have recently eased the programming task greatly, this has been almost compensated for by the much-increased sizes and complexities of the overall software packages required for the newer and more sophisticated installations. The result has been a major shortage of personnel qualified by training, experience, and innovative ability to carry out the programming of one of today's systems. There is thus a major incentive to reduce this total programming load by developing new and more universal programming aids, standardizing them for easier personnel training and use, instituting a ready transfer of successful programs to new computer systems, and exchanging mathematical models and their pertinent programs between different companies and industries.

The goal for the standardization effort can be stated as follows:

As a long-term goal, it should be unnecessary for user-company systems and instrumentation engineers and programmers to have a knowledge of the basic machine language of the computer involved or even of an assembly language for this machine. However, they must be thoroughly grounded in computer and control concepts. They should be able to communicate with the system, construct new programs, and initiate or modify the sampling sequences and data manipulation techniques through the use of a standardized high-level language, through the use of specialized process control program capable of handling simple, tabular formats, and/or through an operator's console in some equally simple manner.

Programming systems adopted should also have long-range goals of machine and configuration independence. They should, in addition, contain provisions for automatic or semi-automatic documentation of all changes to systems programs and/or system configurations.

Table I outlines a set of requirements for such a standardized set of process control programs. Achievement of these goals and requirements will go a long way toward completing the digital revolution in industrial control now well under way.

Table I

Desirable Requirements for Software Standardization

1. There should be available a high-level programming language. For example, a language which includes USASI Standard FORTRAN (X3.9-1966) as a subset should admirably satisfy such a need.

2. The high-level process control programming language should contain the necessary capabilities to permit the following industrial control functions to be programmed completely in this language:

a. Bit manipulation

b. Bit testing

c. Process interrupt handling

d. Interrupt inhibit and permit

e. Parallel task execution

f. File handlings

3. The goal of software design should be to minimize the amount of specific information which a process engineer needs to know about a control computer and its associated software to implement computer control for a known plant.

4. Specialized process control programming systems should be developed which carry out the following:

a. Make the organization and development of a process-control computer system as simple as possible;

b. Contain an organizational method by which the user can carry out any functions possible with conventional control systems with only a very minimum knowledge of programming such as by using a "fill in the blanks" technique;

c. Preserve at least as much compatibility between the control practices of different industries as is possible with conventional analog control hardware;

d. Permit on-line addition or deletion of inputs, control computations, outputs, and changes of coefficients, without recompilation or reassembly.

5. Variable names, etc., should conform to ISA Standard ISA-S5.1, 1968.

6. Software systems should be developed in a modular fashion to the maximum extent possible with the functions of the modules rigidly defined. These modules should communicate through tables to the extent possible. Table format should be such that they will permit substitution of complete blocks as newer, more efficient forms are developed and allow reassembly of the program without the necessity of reworking the other blocks. Figure 1 presents one form which such a system might take. This will permit standardized software to be used in a multicomputer system.

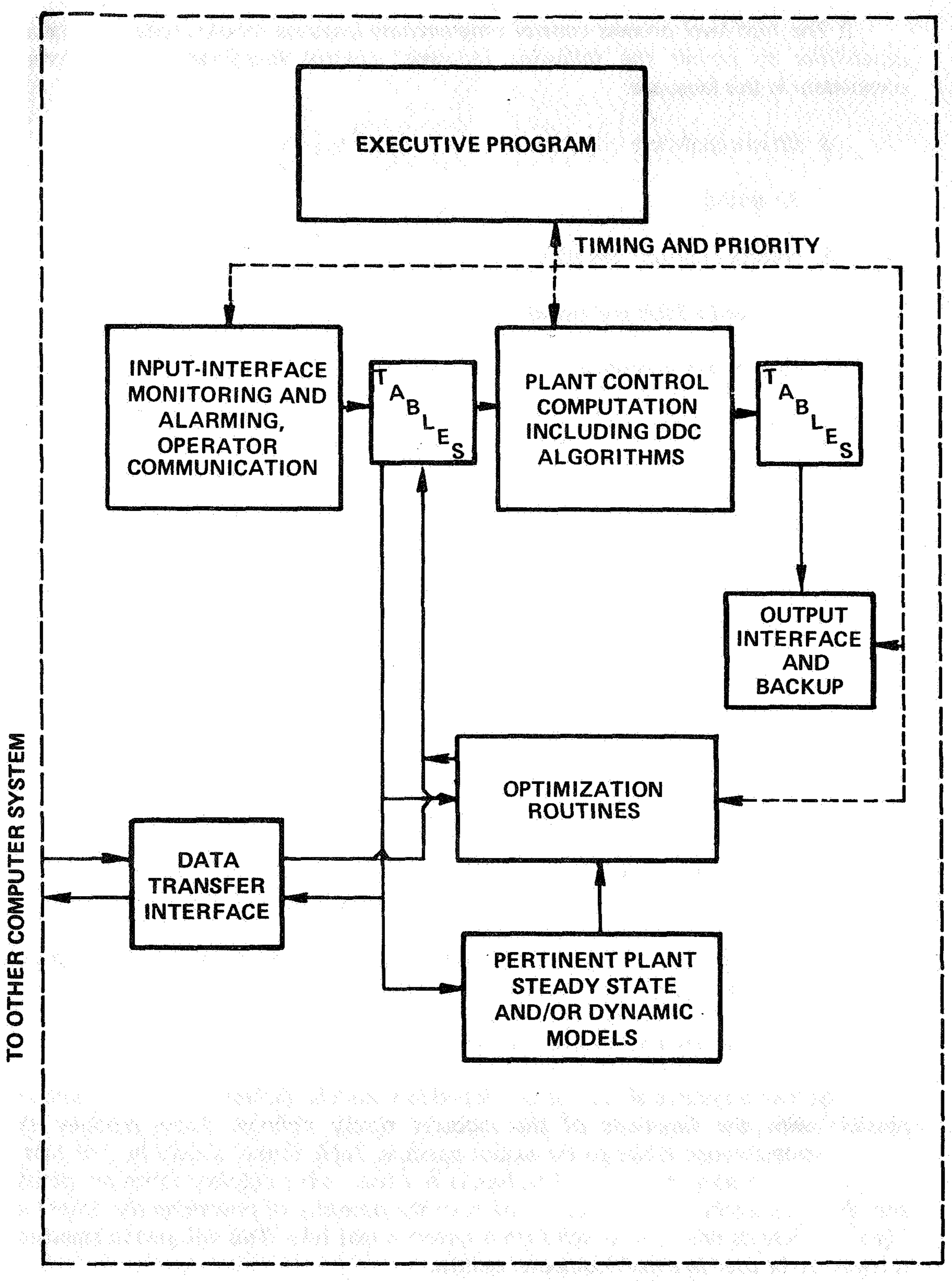

Figure 1. Block diagram of proposed industrial control program system

OVERALL COMPUTER CONTROL SYSTEMS: HARDWARE AND SOFTWARE

Recent trends in the manufacturing industries have shown the desirability of, and, indeed, have revealed, a great effort on the part of both users and vendors to perfect a hierarchy type of overall computer control system which integrates first-level or direct digital control with plant supervisory control and finally with the company level or management information system computers. This would operate somewhat as outlined in Figure 2. Full implementation of such a large-scale concept must await the full development of the all-digital systems mentioned earlier for their economic realization. They must also wait on a major effort in software standardization for them to be practical systems in terms of the personnel committment involved for systems mathematical modeling and programming.

Work already done in this area, along with the foreseen developments and improvements in digital systems, makes their full-scale use almost inevitable as management seeks an ever wider and more immediate control of a company's operations and an ever better means to react to changes in the market place and in the capabilities of competitions.

Predictions are continually being made in the technical press in an attempt to foresee the path which future technical developments will take and how they will affect the degree of implementation. Computer control has received even more than its usual share of speculation. Some of the resulting proposals concerning the form of future computer control systems are most intriguing, while still being quite technically and economically creditable. One such system has been recently proposed by Stanford Research Institute personnel as a result of their major survey of the process control industry.

Making use of the full digital techniques mentioned earlier, they developed the following concept and related costs for a 1250—loop digital control system for a large industrial plant, such as a complete petroleum refinery. This is sketched in Figure 3. Table II outlines the characteristics of the machines involved, while Table III presents the expected costs for the system as compared to a similar system today.

Note that the 1250 control loops are distributed equally for convenience between five separate direct-control computers. Each of the remote multiplexers has about 25 inputs and transmits information to the control computers digitally. These, in turn, can transmit information on to the supervisory machine. Note also that the crossbar in the large machine, plus the appropriate provision at the small machines, will allow all information coming to one of the small computers to be transmitted to the standby computer, should the former fail for any reason. The large disk of the supervisory machine would contain an image of the program on each small machine for instant transmission to the backup as it is needed.

Should these predictions come to pass by 1975, as expected, they will very nearly meet the requirements which have been made previously for full acceptance of digital process control systems in the United States, which are listed below. Digital control systems will replace analog control systems for essentially all new plant situations, provided:

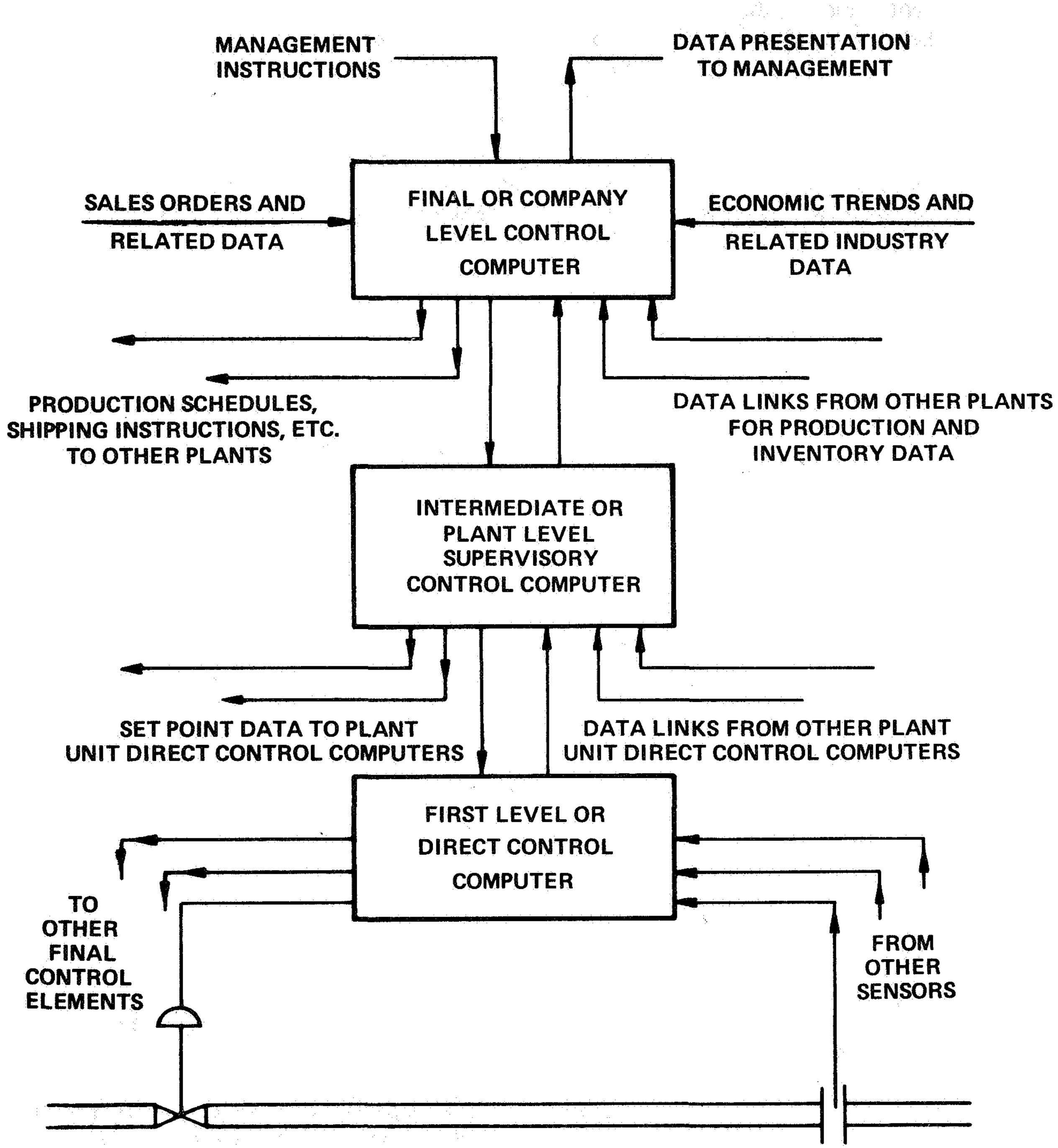

Figure 2. Hierarchy control as applied in the process industries

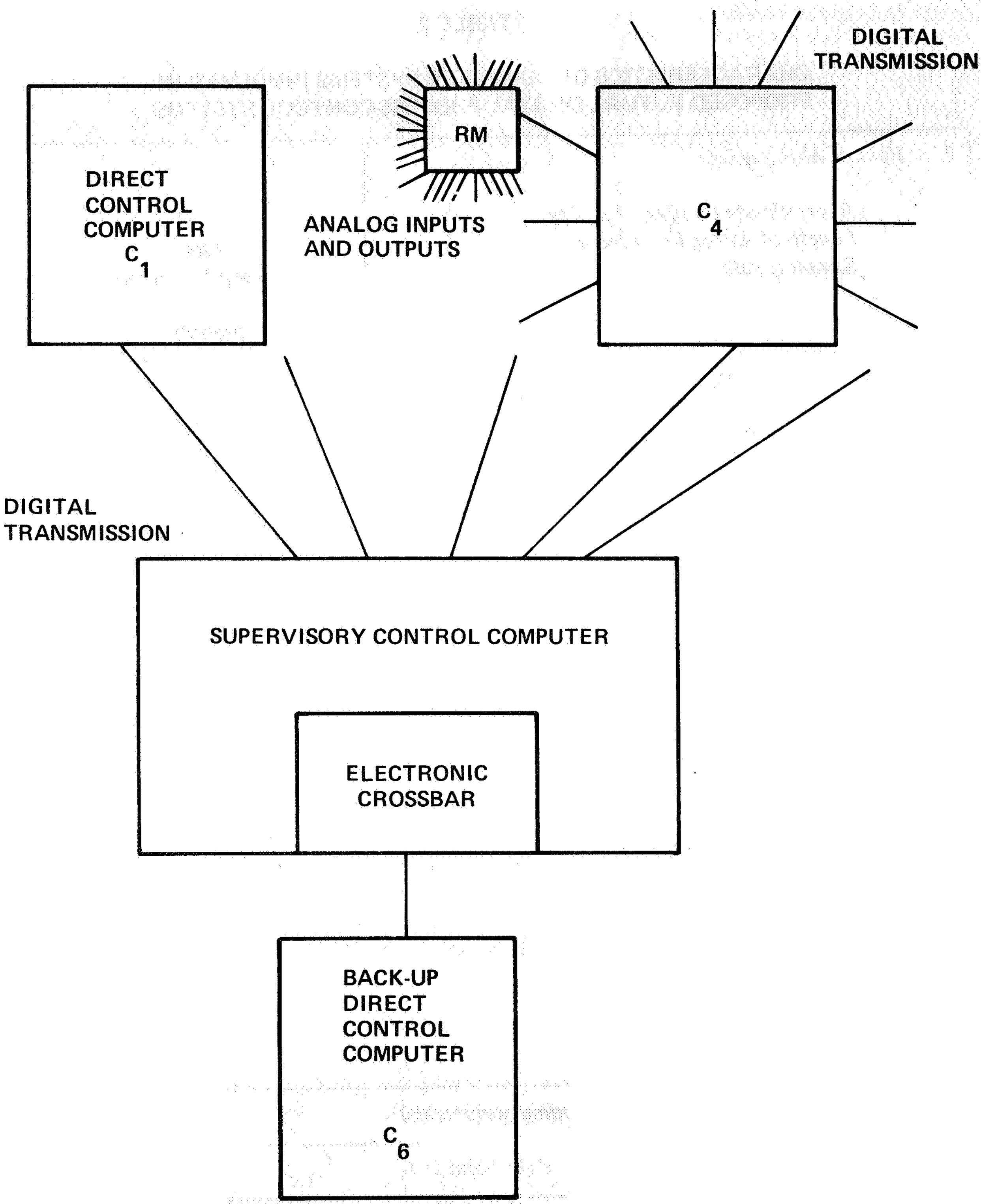

Figure 3. Prediction of digital process control system of the next decade

TABLE 2

CHARACTERISTICS OF COMPUTER SYSTEMS INVOLVED IN PROPOSED FUTURE DIGITAL PROCESS-CONTROL SYSTEMS

1. *Remote Multiplexers*	
Approximate number of inputs	*25*
Length of analog input leads	*<100 feet*
Sampling rate	*Very fast because of burst-mode operation*
2. *Direct-Control Computers*	
Total inputs each	*~250*
Memory cycle time	*0.5 μsec*
Organization	*Parallel*
MTBF	*10-20,000 hours*
Memory size	*32 kilowords*
Word length	*18 bits*
3. *Supervisory Control Computer*	
Memory cycle time	*0.4 μsec*
MTBF	*5-10,000 hours*
Memory size	*160 kilowords*
Bulk memory (disk) size	*5 megawords*
Word length	*36 bits*

TABLE 3

PREDICTED COSTS OF PROPOSED FUTURE DIGITAL PROCESS-CONTROL SYSTEM

1.	*Direct digital control computers*	*$ 25,000 each* *$150,000 total*
2.	*Supervisory control computer (including peripherals)*	*$150,000*
3.	*Instrumentation wiring and distributed A/D and D/A*	*$250,000*
	Total:	*$550,000*

Compares with a total cost of $2,500,000 to $3,000,000 for an equivalent third-generation system at today's prices.

1. A five-fold increase in basic machine speed is achieved over third-generation hardware (now 1.75 to 2.0 μsec memory cycle time);

2. A four-fold increase in reliability is achieved over third-generation equipment (now 2000 to 4000 hours MTBF for all electronic equipment — not electro-mechanical);

3. A five-fold decrease in computer-system costs over third-generation equipment (now \$250,000 to \$400,000 for typical application equipment of single machine for 50 to 250 loops).

In implementing these larger and more advanced systems it is expected that the user companies will be doing all the specialized programming required for the system themselves. However, this will be much less than that necessary today. In addition, it is expected that much more use will be made of the modern control theory now being produced by our university and research organizations but at present getting little use in industry. The further research now going on, plus the increased capabilities of the machine used, should solve the problems now hindering the wider application of control computers.

BIOLOGICAL OCEANOGRAPHY

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* * * * *

My presentation is concerned with the problems of biological oceanography related to sea productivity. These problems are best attacked in an indirect way. Situations in the ocean that are conducive to productivity and thus to a successful fishery are sought, rather than attempting directly to find the fish themselves.

In order to do this, the ocean must be understood; at least the part of it that is sunlit, because this is where all the photosynthesis takes place. This is where the whole food chain starts. This focuses attention on the upper 100 feet or so of the ocean -- the region where light penetrates in sufficient strength to produce more biologically useful products than are being used up. The balance point is at this so-called critical enphotic depth. Below, plants may still be able to photosynthesize, but they consume more than they produce -- instead of producing surplus oxygen, they are operating at an oxygen deficit. So, this is the bottom of the layer of interest when we are referring to biological productivity. The productive region comprises only 1 percent of the ocean, but it is an extremely important fraction. It is also the fraction that people sail in, that people fish in, that breeds the storms, and that part with which meteorologists are concerned. All the significant energy that flows into and out of the ocean goes through this upper 100 feet. Thus, it is by no means trivial to sample and study only the upper 1 percent of the ocean.

To put the assessment of food resources of the sea in proper perspective, it is useful to compare the sea harvest with that of the land. This is summarized in Table 1:

TABLE 1

COMPARISON OF FOOD PRODUCTION IN THE SEA AND ON LAND*

Million Tons Harvested Annually					Annual Dollar Value (billions)	
	U.S.		World		World	
Method	Ocean	Land	Ocean	Land	Ocean	Land
Gathering	0.01	2	0.02	100	0.04	5
Farming	0	230	0.01	2000	0.01	100
Hunting	1.6	1.3	29	27	4.4	11
Herding	0.01	85	0.6	520	0.2	120

(*From Iselin & Emery, Science, Sept. 15, 1967)

It is readily apparent that the only significant ocean food gathering activity is hunting which is characteristic of undeveloped technology. One of the reasons for under-exploitation is that much of the ocean is quite sterile. Vast areas of the sea are stable, that is, hot on top, cold on the bottom, with little overturn to interchange nutrition and exhausted water. We conclude, therefore, that, on a caloric basis, the ocean cannot by itself solve the world food problem.

More realistically the ocean may be expected to contribute significant amounts of protein, especially animal protein that contains essential amino acids not abundantly furnished by edible grains. To a limited extent, the efficiency of our food harvest can be enhanced by the changeover from hunting to farming methods and, for a limited number of species such as oysters and lobsters, this will be quite feasible. But, by and large, we must depend on finding fish wherever they congregate in the sea and in this activity satellites may be able to assist fishermen in a significant way.

INSTRUMENTATION IN OCEANOGRAPHY

Modern technology has provided us with many new techniques to help us understand the oceans, how they circulate, and how fish travel in the great patterns of moving seawater. I have chosen the unmanned, instrumented satellite to illustrate the value of technology in helping man find more food.

What do oceanographers want to know about the ocean, and which are the significant parameters to measure? Oceanographic parameters fall into three broad groups. The physical state of the water, which ordinarily implies its temperature and pressure, should be known. However, in the upper 100 feet pressure is of no concern, and the physical state of the ocean, therefore, is determined by its temperature and, to a lesser degree, by its salinity. The second group of parameters has to do with the material constitution of the ocean; what chemicals are dissolved in it, what biological matter, what particulate matter, and what colloidal matter it contains. Finally, the third class of parameters has to do with the motion of the ocean, and the resulting shape and roughness of the surface.

The instruments available to measure these parameters fall into five or six general classes. One class is comprised of imaging devices, such as cameras, infrared imaging radiometers, and imaging radars that tell the position and the two-dimensional properties of things. Next, there are frequency-analyzing devices of the general class of spectrometers, whether operating in the optical, infrared, or the microwave region.

A third category has to do with pulsing devices that are generally designed to find distance and, hence, can add the third dimension of shape. These include pulsed lights, pulsed lasers, and special types of radars. A fourth category is comprised of passive radiometers that operate in various bands of the electromagnetic spectrum, from infrared through microwaves. These are used to measure the total emitted energy so as to arrive at the radiation characteristics that basically depend on the temperature and roughness of the ocean, and, to a small extent, on its salinity. Finally, a fifth category comprises scatterometers that measure the scattering cross-section of the ocean surface and, thus, give information about the steepness of surface waves and about the sizes and curvature of the particles or facets that are back-scattering the energy. When looking at something much smaller than the wavelength, Rayleigh type scattering is obtained. If the particle size is commensurate with the wavelength, dispersion effects due to Mie scattering are evident. The colors of colloidal dispersions are examples of this sort of scattering.

Finally, if the scattering particles are much bigger than the wavelength, ordinary specular reflection occurs. In the latter group, there are instruments with various resolutions, from glitterometers that measure the sun glitter of very small waves to radars that look at somewhat longer waves, and out into the medium radio frequencies that respond to the long waves on the ocean. A possible sixth category includes the telemetering buoys which exploit the communications capabilities of satellites rather than remote sensing. If the six groups of instruments are arranged against three different classes of oceanic parameters—that is the thermal, the frequency, and the kinematics—the end result is a matrix of 18 pairs of instruments married to particular parameters. This is a broad-brush treatment of the way oceanography instrumentation may be classified.

WATER TEMPERATURE

Figure 1 shows the northwest or cold wall boundary of the Gulf Stream. The Naval Oceanographic Laboratory has marked where the propoises were sighted; where whales were seen; where there were birds; and where there were schools of fish. It appears that there is an intimate relation between the distribution of fish and their predators and the surface temperature of the sea.

The ocean, because of sun heating, becomes stabilized. It is an extremely stable medium compared to the air. If it were not being stirred up in some way, and there were no convection going on, within a very short time all the nutrients of the upper layers of the ocean would be used up by the plants and animals under the influence of photosynthesis. These, when they die, sink out of the upper layers and remove the nutrients as they go. Without upwelling the upper oceans would become extremely sterile within a very short time. The tropical oceans are very blue for precisely this reason--that they are very sterile. In order to find areas of biological productivity, therefore, places where the sea is being stirred up must be found. As shown, along the northern wall of the Gulf Stream, there is a very intimate relation between the sightings of porpoises, which are excellent and expert fishermen, and the boundary of the Gulf Stream.

In looking for areas of upwelling, temperature is the best indicator. The reason that the Grand Banks off Newfoundland are such a fertile area (probably the greatest fishery in the world) is because the warm tropical waters mix with waters coming down from the north that carry melted ice from the glaciers and runoff from all of our eastern rivers. This juncture is an extremely profitable place from the point of view of biological productivity. This is the kind of thing that is being sought with satellite temperature sensors. On a ship, salinity and other parameters might be used. Figure 2 is an infrared image of the cold wall of the Stream as seen from a low flying aircraft.

Since there are large parts of the world where there is really not much information, satellite technology will be a great boon if it can be made to work.

Moving to a different part of the world ocean, the Peru current upwells along the coast of South America, producing the highest rate of biological productivity ever found anywhere in the ocean. This is the region where the anchovy fisheries have brought Peru, within the last 10 years, from something like eighth place in the world up to first place in fishing. They have surpassed Japan, Russia, the United States, and everybody else by exploiting the fishery that occurs in the Peru current. It has been found recently that this zone extends across the South Equatorial Pacific region, and here there is a fishery--a potential one--that has never been exploited, all the way across this zone. This is due to upwelling. Also shown is the tropical convergence where the winds from the Northern Hemisphere and the Southern Hemisphere intersect.

Figure 3 is an Applications Technology Satellite (ATS) picture of this same area that was taken a year ago last May. A productive region of cold water is visible. During the time that this condition existed in Peru, the biggest congregation of tuna fish ever recorded occurred. It is possible that the strength of the offshore component of the land-to-sea breeze carries the clouds offshore and by a sort of image circulation brings water up to the surface, sweeps the surface water away,

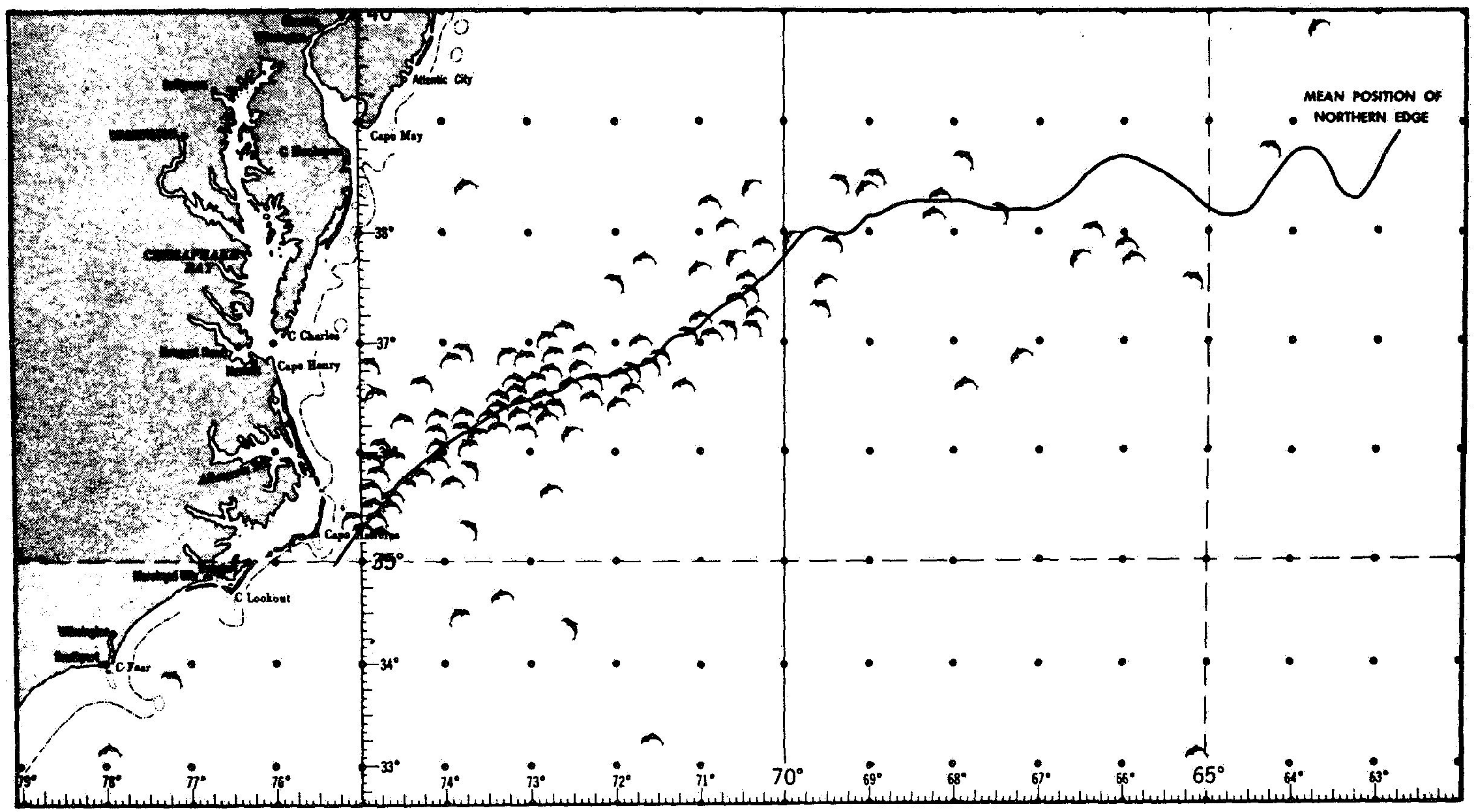

Figure 1 — Porpoise observations along the Gulf Stream

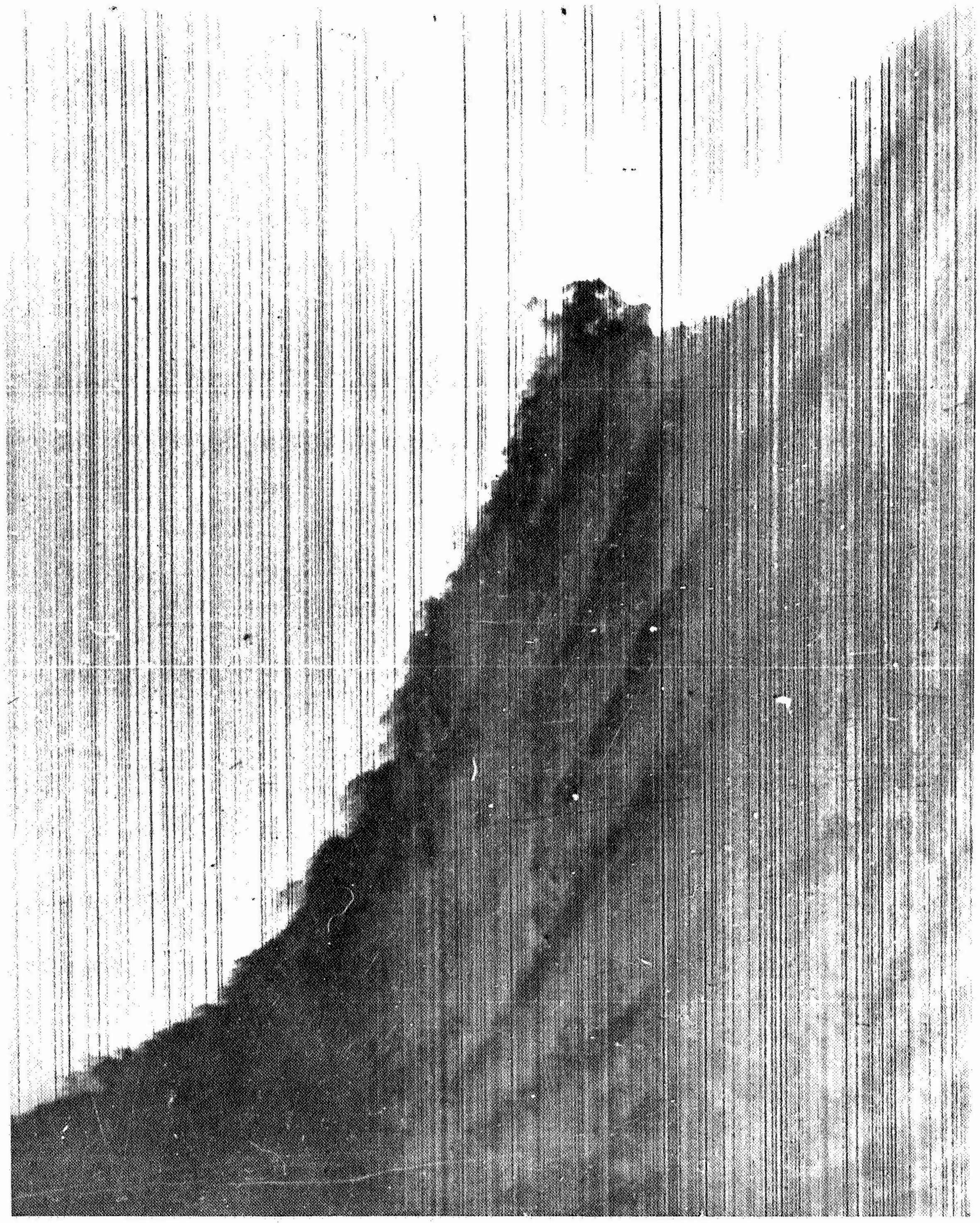

Figure 2 — IR image of the Northwest Wall of the Gulf Stream taken from an aircraft; warm water is dark.

Figure 3 — ATS image of the western coast of South America, the Peru Current, and the South Equatorial Current.

and brings cold nutrient-rich water up along the coast. This effect is also typical of the Santa Ana wind in Southern California. Perhaps something about the intensity of the upwelling can be found by studying the behavior of the clouds shown in satellite photos.

The effects of the weather on the sea are not well known because most air/sea interaction studies to date have been directed toward finding out what the ocean might be doing to the air rather than what the air might be doing to the ocean. This is a somewhat inverted point of view, because the ocean is basically driven by the air. It is "a sluggish tortoise following a fast rabbit." They are hitched together by a sort of flexible leash. The things that happen in the air happen some 10 to a 100 times faster than they do on the ocean. The ocean reacts only to a series of storms that go by, and these would have to be studied over a period of a week or so before finding what the response of the ocean might be.

Figure 4 is a picture of the Gulf Stream showing, in addition to where it is, how it meanders from day to day. The dotted line is the mean position of the western cold wall of the Gulf Stream on the 1st of April, and the solid line the position of the wall on the 30th of April. The differences here are of the order of 120 miles.

A more detailed picture of what happened to the wall in between times is shown in the inset of Figure 4. Its position is shown for April 8, 11, 12, 18, 22, and 27. This is a meandering stream, therefore, that is extremely important to the business of the fisheries and to the weather.

Since infrared is put out of action by clouds, it would be advantegous to develop a temperature-sensing capability at radar frequencies to which clouds are transparent. A calculation by David Staelen of M.I.T., showing the apparent or brightness temperature, referred to the molecular temperature at different frequencies over smooth water looking through atmospheres of varying composition. The wavelength of the microwaves is very critical. The conclusion is that the wavelength must be as long as possible, because at short wavelengths there is a lot of interference from the atmosphere. Microwave frequencies around 3 cm or more are the most helpful in this regard.

The energy available from radiation depends, of course, on the temperature of what is being observed. The maximum energy received through our atmosphere from the sun is peaked in the near infrared at a wavelength corresponding to a temperature of about 2000°K. Now, the ocean temperature is about 270 to 300°K, and the radiant energy peak is in the 10- to 15-micron window of the far infrared. This is why radiometers are generally made to operate in that frequency band. Out in the microwave wavelengths, the energy curve decreases rapidly and the energy available for sensing becomes very, very small so that, at first glance, the idea of using a microwave radiometer for looking at ocean temperatures does not seem feasible. Luckily, however, a radio receiver can be built that is much quieter than an infrared receiver. The noise, therefore, decreases with the signal strength. The result is that things are not very much worse in the microwave than in the infrared. The great advantage of developing the microwave technique for measuring sea-surface temperatures is that it would be virtually all-weather--certainly all-weather as far as light fog and stratus clouds are concerned.

Satellite thermal pictures occasionally show an eddy breaking off from the Gulf Stream. When these eddies are shed, they lead an independent life on their own because there is nothing to stop them. The viscous forces of the ocean are very weak. One particular eddy was kept under

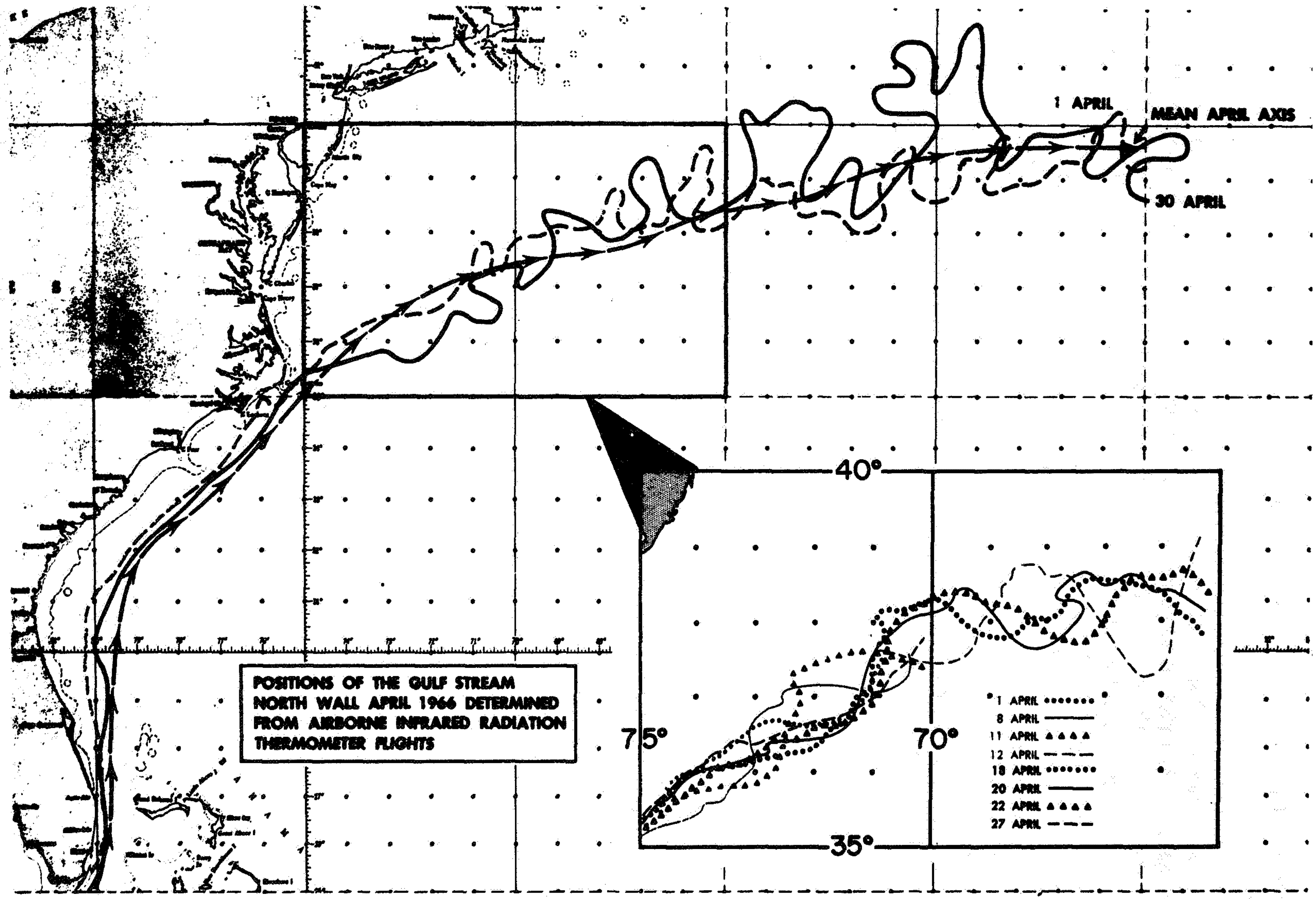

Figure 4 — Gulf Stream position.

observation by the Woods Hole Oceanographic Institute and ESSA for approximately 6 to 8 months.

An example of space-obtained data that has been used in oceanography by professional oceanographers is a picture made by Nimbus I when it first went up in November 1964. It showed the Antarctic pole, the edge of the Antarctic ice, and the sea ice. There were water leads and an open water lead around the margin of the continent. Professor Walter H. Munk of the University of California was working on the problem of the rate at which Pacific water of intermediate depth is supplied to the Pacific Ocean. This is a classical oceanographic problem. The source of this water is the melt-back of the ice shelf in the summertime. And, although there is good information of its extent in the summertime, there is almost no winter information. A Russian ship once made this hazardous trip in the Antarctic winter and found the outer limit of the ice at one location; this was one data point, and it was all there was in the literature anywhere. The Nimbus satellite, in a single pass, took a photograph clearly showing the outer limit of the ice shelf in the middle of their winter. Professor Munk used these measurements to compute the volume of ice that had been melted and added to the Pacific Ocean. This is an example of temperature data from a satellite which would be otherwise unobtainable because of the inacessibility of the region.

WATER COLOR

Water color is another ocean parameter that lends itself to satellite observation. First, it should be established that color has some relevance to the fisheries and other oceanographic problems. Figure 5 is a diagram which was made by Dr. Maurice Blackburn of the Scripps Tuna Investigation in La Jolla, Calif. It shows Baja, California, where the tuna fisheries are heavily developed. As previously observed, fish are sensitive to surface temperatures, so one would not expect to find many tuna in water colder than 20°C. However, there are areas of warmwater where no tuna have been caught. So, temperature alone is not a sufficient indicator.

The missing link is the food for the tuna. Temperature and food are two conditions necessary for a good fishery. Fish were caught where the triangles and dots are shown. The dotted line is the limit of the water which had 0.1 mg/m^3 of chlorophyll in it. The natural history of this picture seems to be as follows. The winds blow down the coast and, as they blow across Point Eugenia, they cause strong upwelling of cold water. This produces the tongue of cold water which comes down the coast of California. This is nutrient-rich water and triggers a whole series of biological events. The first result is the production of chlorophyll which discolors the water. The chlorophyll coincides with the occurrence of red crab, which is an animal grazer, which, in turn, is eaten by the tuna. The occurrence of red crab is indicated by the dotted line in the regions where there is a high concentration of chlorophyll. The fish were caught, therefore, not merely in water of a particular temperature, but in an area which is plentifully supplied with food as indicated by chlorophyll. This shows the importance of color as an indicator of biological activity.

The tropical Gulf Stream water is relatively blue and sterile. Only Rayleigh scattering, therefore, is coming out of it, and it looks quite blue. The adjacent is the slope water, and it is relatively rich. This is the water which has been stirred up as it came across George's Bank and the Grand Banks, and it has been discolored not only by the chlorophyll but also by the other metabolic products of biological activity and the plankton itself. The usual pictures taken at glancing angles of the Gulf Stream show a big color contrast that is not caused by the constituency of the water but rather by surface roughness.

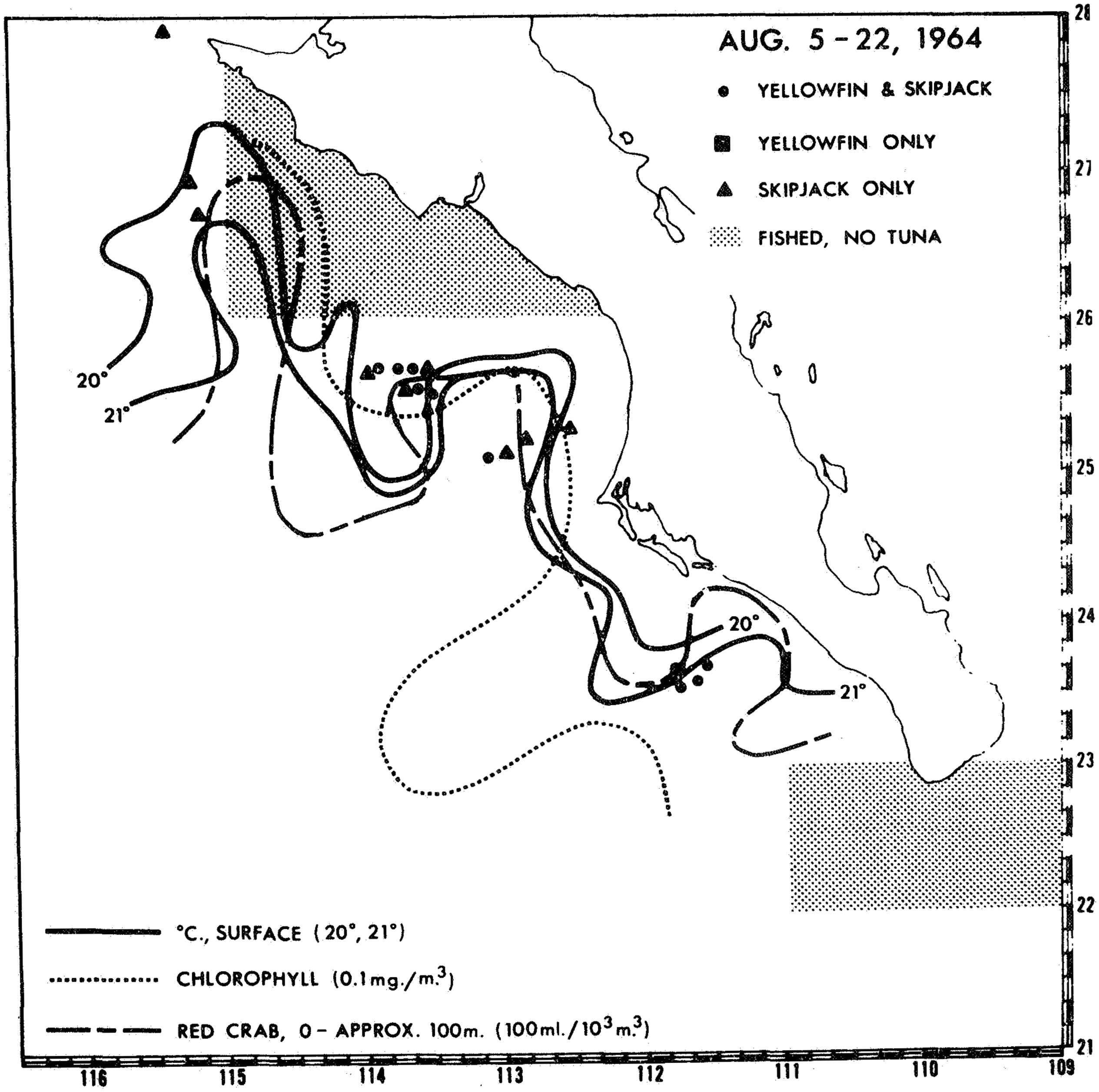

Figure 5 — Isolines of certain property concentrations and positions of tuna catches in August 1964.

However, a view looking straight down shows the effect of absorption of the color on the light that has upwelled from the sea. This is the absorbency that you would expect from a concentration of plankton plants in the water. The water is very absorptive beyond 650 or 750 millimicrons and has a window at 475 millimicrons where it has its maximum transparency. Chlorophyll has a very high absorption, however, in the very region where the water is most transparent, and rather low absorption beyond 500 millimicrons. The result of this is that, whereas the clearest ocean water has its maximum transparency at around 475 millimicrons, the maximum transparency shifts over to around 570 millimicrons as one moves towards the coast where plankton increases.

There is a peak in the red that is characteristics of cholorophyll A, and if it were possible to detect this peak in some way by a clever optical device, it would be very diagnostic, because it would be quite different, for example, from the absorptions caused by mud particles and sand in the water. At the moment, however, this seems rather difficult.

WATER MOTION

Water motion is another property that lends itself to world-wide observation. This is perhaps the hardest characteristic to measure from the air or from satellites. The importance of flow arises from many different interests, among them being its effect in stirring up the water and controlling the distribution of larvae and eggs.

A schematic sketch of a shrimp lagoon, a nursery for the white shrimp, which is perhaps the most valuable of all our sea animals, is shown in Figure 6. The adult shrimp lays her eggs at sea, relying on the normal currents to carry the larvae into sounds and estuaries where they go through their growing cycle in this estuarian environment. As they become adult, they come out into the ocean again, where they are caught. This cycle depends on circulation and on the input of nutrients from the shore. The shrimp industry, therefore, depends on river runoff not only for the transport of larvae but also for their nutrition.

Several of the Gemini photographs have shown the Terminos Lagoon near the big Campeche Banks. The lagoon has two entrances, and the sediments in the water can easily be seen. Water discolorations, probably due to chlorophyll, can also be seen. This is a means of tracking the currents that are carrying shrimp in and out of Terminos Lagoon, which is the nursery area for much of the shrimp that are caught off the coast of Yucatan.

Our experience with satellite observation of the sea has barely begun. But already we find reason for optimism that this technology will soon add a new dimension to our understanding of the upper layers of the ocean.

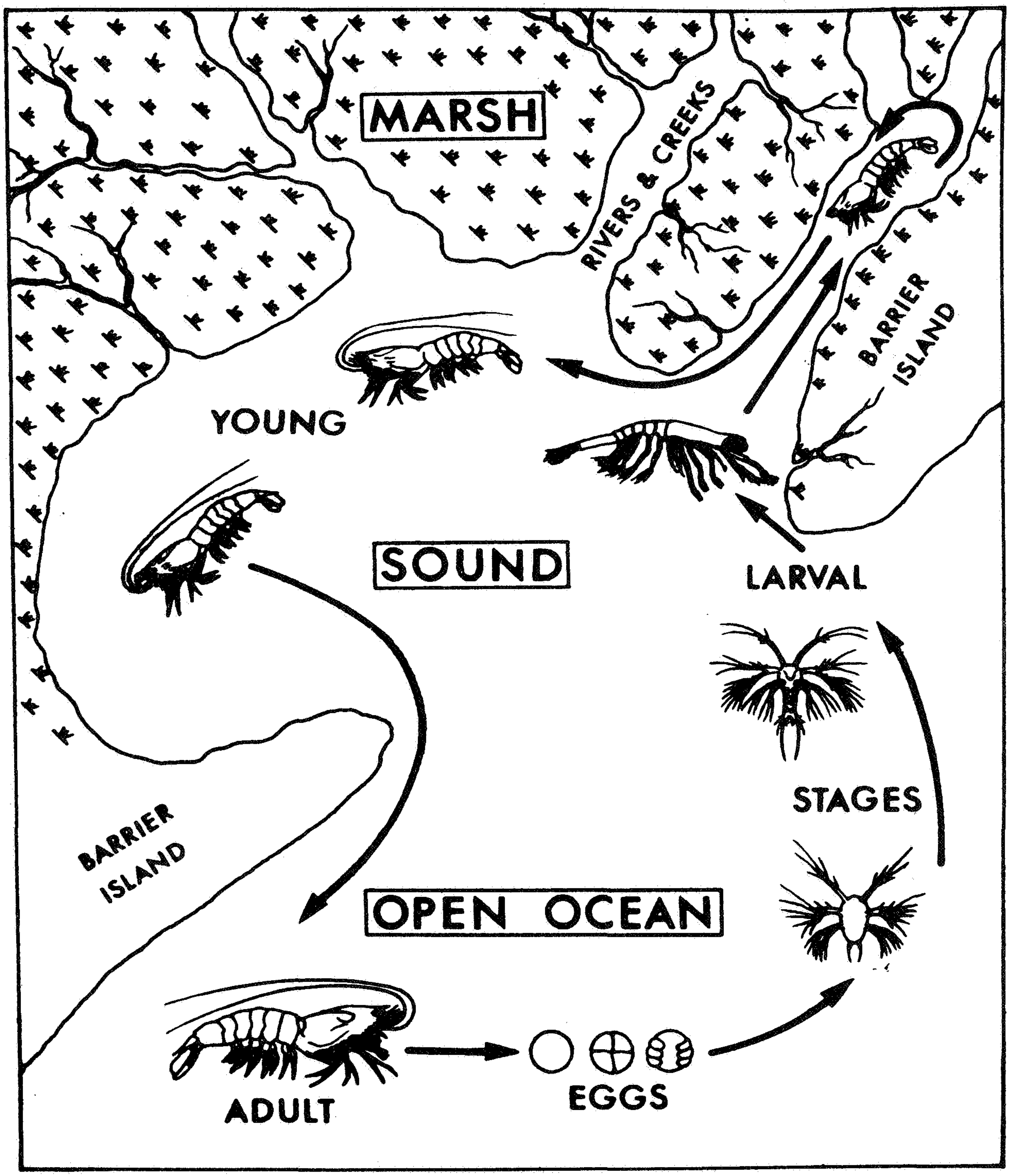

Figure 6 — Diagram of the life cycle of the white shrimp (cycle occurs in a 12-month period)

REFLECTIONS ON GIFFORD EWING'S PAPER

DR. JOHN V. BREAKWELL
Professor of Astronautics
Stanford University
Stanford, Calif.

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We have heard how space age technology is already beginning to be useful in following the motion of fish as well as pollutants--how temperature and color measurements from a satellite may reveal the location of conditions favorable to various forms of marine life.

To what extent and by what means may ocean biology be controlled to our advantage? As Ewing has said, the location of fish can be substantially increased by herding instead of simply hunting. As has been shown off the coast of Japan, scientific improvement of the local nutrients can breed fatter as well as more numerous full-grown fish.

Man's control of his environment will need improvement in other directions--thus the placing of atomic power plants on the ocean bottom, instead of near rivers or coastline, could prevent the present rate of radiation damage to fish from atomic waste. This might at the same time increase fish growth rate because of the rise in temperature, provided that the resulting ecology was favorable.

The pollution of water from all kinds of industrial waste is a serious problem. Here again, conservation of man's "natural" environment is not the real goal, but scientific modification of the ecology. Thus sewage can actually be used to enrich water.

At the risk of stressing the obvious, I conclude by adding that the necessary improvements in man's environment will not be accomplished without some form of control on the local, national, and international levels. I refer here, of course, to control applied in the field of human relations, a field which it is safe to say is very much less understood than man's environment. This indeed is no reason for pessimism. Quite the contrary, in fact!

HOW DO WE MEET FUTURE CONTROL CHALLENGES?

A Panel Moderated by
L. A. ZADEH
Department of Electrical Engineering and Computer Sciences
University of California
Berkeley, California

* * * * *

Professor Zadeh: First of all my main qualification for acting as a moderator of this panel which will discuss methods of meeting future control challenges is that I am not really a control theorist. It doesn't mean, of course, that I don't have many biased views on issues relating to the theme of the panel. I do, and I have expressed them on various occasions. Therefore, I will limit myself to the role of a moderator.

Even though our panel is not complete,* it is a very authoritative one, including Mr. O. Hugo Schuck, Chief of the Office of Control Theory and Application, NASA Electronics Research Center; Prof. Theodore Williams, Professor of Chemical Engineering, Purdue University; Professor E.F. Bisbee, Department of Naval Architecture, M.I.T.; Mr. James Eaton, Head of the Systems Department of I.B.M.; Prof. Yu Chi Ho, Gordon McKay Professor of Engineering and Applied Mathematics, Harvard University; and Prof. Henry M. Paynter, M.I.T.

Now, each member of the panel will express his views with regard to the theme of the panel: "How Do We Meet Future Control Challenges?", and then we will ask the audience to join in the discussion.

Professor Paynter: We have raised a lot of questions, at this Symposium, and I think this was part of the intent — to raise such questions and to find out how many of them are questions in search of answers; and how many are questions for which answers do exist, and for which it is simply a matter of finding out in what areas and by what techniques the answers were found.

We have tools that could provide some help. In the organization of the conference itself, I would like to make a point that despite all sorts of difficulties in the last couple of days, somehow part of the spirit of the organization has definitely come out, namely, that we have been presented some problems by experts within the field, who do not think of themselves, by any stretch of the imagination, as control people.

I think they have presented us with a number of surprising facts, actually, which I for one was not particularly aware of 48 hours ago. I hope we can make an assessment of where we stand within the hour.

I myself am distressed, not so much by the business of the "gap between theory and practice" as the fact that a number of very real problems now are made aware to us; in particular, the problems Dr. Friedman just presented and some of the remarks of Dr. Ewing, namely, that technology alone is clearly not enough and that we may be running out of time. I think we have a responsibility to sharpen up the tools we have in hand to attack these problems, which tell us we had best go to work quickly and rather effectively and efficiently. Perhaps we simply are going to have to reject those parts of the problem where we cannot expect to attain useful answers within the time scale allotted to us.

Professor Ho: I will make only one statement. It seems to me as a result of the various remarks made today, science and public policy have become inseparable for us both as citizens and scientists in the future; this is a question we have to address ourselves to.

Dr. Eaton: I think we all see that there are many systems, many things that could be called control problems, if you take the point of view that anything that needs controlling constitutes a control problem. Where I think we might get caught short is when we begin to look at the problem.

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*Because of inclement weather, such authorities as Frank Lehan, Assistant Secretary for Research and Technology, U.S. Dept. of Transportation; and Roger Levien, Head of the Systems Science Department of the Rand Corp., were unable to attend the Symposium.

Actually, the control is the most trivial part of it, at least control from the point of control theory. If we are to meet the challenges, if we are to make progress, then we have got to step back and look at what the real problem is that needs solving. What has to be done to bring the problem to a point from which or to which we can apply control theory. I think that this does indeed need to be done by control theorists.

Let me even say or put it in terms of modeling, because if the modeling is done by people in other fields, there tends to be a communication gap in that sometimes the wrong things are modeled as far as control is concerned. That we need to know.

We have certain things we need to know in order to be able to control something. Perhaps bringing the philosophy of control to the study of some problem is a very important thing. I believe that statement that it is very important.

I would like to make, because of some earlier comments today, just some brief comments about simulation and modeling. I see two reasons for simulation. One is when I have modeled, I really truly believe the results, but the model is so complex that I can't really see the implications of that model and I can't work out the implications of that model simply on paper.

Let me give you an extreme example of that. We have a fellow at the IBM Research Laboratory at San Jose who essentially starts with short inertia equations and does chemistry on a computer. Now, most of us believe short inertia equations pretty well. We don't question them, not seriously at least, for most of the things we want to do. Yet, it is clear that in just looking at the equation, we don't understand the implications.

There is a point when it pays to go to a computer and to have some simulation. There are a few places in control where that is also the case, where we really know the details but the overall system is so complex we don't understand the implications of that detail.

I think in the problems we have heard about today -- let me call them poorly defined problems -- I don't think that is the case. I don't think we know the details from which we can draw all these implications. The situation is quite the converse, namely, we observe some of the solutions. We observe the system and see what happens, and the real problem is to go back and try to build a model or structure that explains what we have observed. Of course, the only reason that we are really interested in that is so we can predict the evolution of a system and predict what will happen if we make changes in the system.

I think that the real problem that we have in simulation is what I call the inverse problem of going from observations and the things we see around us to some more fundamental description that can be used to predict the evolution of the system.

Professor Bisbee: I would like to present an area of problems for the control theorist, namely, those of transportation in a very underdeveloped area. There, the problems to be dealt with are really trivial in terms of control theory. They are nonetheless interesting and fascinating in that they occur in a place where they are not really supposed to. When you speak of control theory and transportation in one breath, your mind immediately conjures visions of fancy vehicles and nice ways of making them move. I submit that some of the problems cropping up, which are of interest to control theorists, are not these but something else rather unsuspected.

I was initially brought to this meeting to make some comments on a very interesting talk by Mr. Lambert, in which he outlined some of the activity in the air transportation field. I hope his talk will eventually get to you in a form that you can read because, in reading it, you can then see in chapter and verse some of the things that I am going to speak about.

Let me just note in passing some of the interesting things that happened for control theorists. First, the construction of transportation facilities; these are usually built to meet some demand assessed in one of a variety of ways. On completion of the facility, one sits back to watch the new behavior level generated as a result of that completion and notices events quite unrelated to the prediction problem stated at the outset.

Again and again we find facilities, the capacities of which are too small to handle the demands. The obvious feedback principles, which are inherent in this supply-and-demand interchange, were wholly ignored by those planning the transportation facilities.

The second thing of interest to the control theorist is the treatment of capacity in a transportation system, a factor largely associated with your attitude toward congestion in transportation. If you believe that congestion can be obviated in some means, then you are less interested in the problem. But if you tend to see it as a question of a functional relationship with respect to the utilization of facilities and the measure of awkwardness of that utilization, then you can see capacity and congestion in a wholly different light. I suggest that it will probably never be obviated in human systems. You simply can't get away from congestion. The question then, is, how do you manage it.

The other aspect of interest to control theorists is the time-variant behavior of the user of transportation systems. They don't want tomorrow what they wanted yesterday, and these changes in tastes and usages are largely unpredictable.

Finally, I should say the thing that interests me most greatly – and is indeed the place where the traditional interests of control theory could be best applied in the technology of new systems we find rising around us – is in the study of the operations of those new transportation systems. Such studies should point up the very important aspects of feasibility of viability of a system in ways quite different from conventional economics – the focusing on the day-to-day meshings and gnashings of the global transportation system. These ideas are then, to my mind, focused on the most interesting area of control theory, which is the development of specifications for the control theory problem itself.

Professor Williams: I think, as far as the chemical and petroleum areas are concerned, our major problem by far is the problem of modeling. Really the problem is one of reducing the problem down to a manageable set of equations. One that can be solved not only for the mathematical solution, but within the economic parameters of industry itself; in other words, the ones we can afford to solve.

The process control problem turns out to be not one of stability, which of course is still very important in the aeronautical field, but rather one of economic optimization in both static and dynamic senses, both online and offline. Control sytems should, therefore, be used, not to stabilize the control, but instead, to coordinate very large systems, such as chemical plants or refineries, or even several of these, in order to give the company the maximum economic return along with (if possible) the maximum freedom to follow the changing consumer demand, such as the changing ratio between fuel oil and gasoline between summer and winter.

The knowledge which is paramount here is, therefore, knowledge of the process more than knowledge of the control theory. Therefore, the ideal person to do this kind of work is the fellow who is a chemical engineer with knowledge of control technology in addition to this rather than the reverse.

Mr. Schuck: I would like to emphasize this point. Back in the 1930's, I remember a discussion between some graduate students, one of whom was myself, who were so enthused by the wonders of electronics that they were quite convinced that almost anything could be done with electronics. One of the things that resulted from this attitude was that the electrical engineers decided they could solve the medical profession's problems. They defined just what these problems were to their own satisfaction (which had a lot to do with whether or not they saw solutions), and they were rather surprised when the reaction of the medical profession to their rather arrogant offerings was lukewarm. The problem was that they hadn't gotten to understand the real problem, and the medical profession understandably said: "You have made a nice solution to what isn't the problem."

I think this actually set back the course of cooperation between the electrical engineering profession and the medical profession by somewhere around 15 years. I am hoping, as I certainly sense in many of the statements that have been made in this meeting, that we start out as control people to conduct ourselves with appropriate humility. We must try to learn from people who really know what their problems are and, without losing any integrity on our own part, still mould our behavior in the terms of the real-world problems.

Professor Zadeh: We have gone through the first round. Instead of giving members of the panel a chance to take issue with each other, I should like to call on the audience, first, to see if somebody would like to comment on what the panelists have said or perhaps to bring up another issue, something that the panelists have not touched upon.

Professor Gustafson: I would like to touch perhaps redundantly on the problem of modeling. A few have talked about the difficulties of modeling large-scale systems. One topic that occurred last night was whether chemical processes are now designed for computer control rather than manual control. The answer was that "No, chemical processes were still designed so that they could be controlled manually." There hasn't been this transition.

I think that the same type of thing has occurred in modeling. There is really a gap between the systems which can be successfully modeled by one person and those large-scale systems, where you have many small pieces of the problem, such as an input-output model or an economic system, where all these pieces can be put together and the resulting system is just too huge for simulation in an economical fashion.

To me this represents a gap. You have got a large-scale system. You have got an economic problem as far as being able to simulate it. Instead of taking the traditional manual way of getting somebody in there who knows the system and can make the Gordian knot assumptions that simplify that particular large-scale system, I submit that there are machine ways; there are techniques of using a digital computer to take a large-scale model and automatically simplify it down to a size where a present-day digital computer can be used for simulation and can run control studies on it.

Yet, because you have a tieback with the large-scale system, you are actually working in the world of real parameters – real things that you can get your fingers on.

Professor Zadeh: Before we leave this particular subject, I wonder if any other panelist would like to comment on this particular issue?

Mr. Eaton: Well, I obviously believe that a lot can be done to work the so-called inverse problem going backward from observations or from the implications of the complex model down to a simpler model – but I really question that for control purposes you want a simplified model. What you are really after is a control law.

The only reason we bother with modeling for control purposes is that we don't know any other way of doing it. If I give you a perfect control law, you wouldn't care what the model was. So there are intermediate steps and it is not clear that we want to leave them in this same form that we traditionally have.

Dr. Victor Levadi: I would like to go on record again as being in strong agreement with what Hugo Schuck has said. But I do want to take issue with something else that has been said today, and that is with regard to the question of simulation and the results that can be achieved therefrom.

I think that we can find some very simple situations or problems that can be expressed analytically but which cannot be solved economically by simulation. I think Professor Ho is very familiar with one of these; the dynamic problems associated with differential games. The six-degree-of-freedom, air-to-air combat problem, for example, which might be expressed relatively simply analytically, but some of the problems of simulation are just horrendous and they cannot be economically simulated. I would like to submit that some of these relatively simple models cannot be simulated economically, and we should not look to simulation as the cure-all for our lack of analytical ability.

Mr. Eaton: I hope you are taking issue with me because I don't think I said anything against that. Clearly, you can define some problems very well, but when you boost the dimension by one, you are not going to touch it with a computer. I was trying to break simulation into two categories: one where you know the model and one where the objective is to find the model. I did not wish to imply you can solve everything with simulation.

Professor Paynter: Since we are probably never going to leave the simulation question forever and satisfactorily answer it, I thought a couple of points were raised that are rather important. One is that we have not been noted for making any kind of systematic attack on what really is a paradox or a dilemma: namely, all of us have experienced situations where the results of implementing a system have been such that it either succeeded for reasons not really understood or failed for reasons not anticipated. Until we systematically approach the problem of finding out the minimum we need to know to succeed in a problem as opposed to how much we would like to know to be sure of our answers, we are going to leave a lot of these questions open forever.

I wanted to point out that the remark Dr. Friedman made was very appropriate to most of what we ourselves have done; namely, that when we have succeeded in any large enterprise or large system, I am sure that in most cases we cannot honestly say we understand why the system works. The history of automatic control, from roughly 1920, say, to 1940, was premised on the basis that you could use universal control laws, let's sav, three-term controllers, and somehow achieve some success without really understanding the process that we were controlling. It was a general-purpose controller and it often worked.

Professor Zadeh: I think Bellman put it aptly. He said that the aim of modern control is to achieve partial control under partial understanding.

Professor Ho: On the subject of differential games, what we know about the theory of differential games is so little that not only can we not simulate them but we can't solve analytically many of the simplest problems we formulate. However, I think this should not stop people from working at this. Perhaps, I was partially misunderstood in my remark earlier.

I think, on the other hand, we should work on these difficult problems, but, on the other hand, we should not delude ourselves into thinking that the things we are working on will immediately revolutionize the world and solve many of the outstanding problems. The reasons I work on differential games is not because I think that they will solve immediately the problem of aircraft engagements or antiballistic missiles, but rather add some additional understanding to these problems.

Mr. Schuck: This really goes back to Professor Gustafson's remark on the difficulty of modeling. The usual process, when one sets up a model for complicated situations, is to identify the little boxes in terms of inputs and outputs and connect them with the proper information flow and then simulate this on a computer. That is the way it is stated.

Implicit in this statement is the need for identifying specifically and concretely the input-output functions in the various boxes, the functional boxes. And here is where you really get into difficulty because in so many cases—as distinguished from a simple weight on the end of a string—you cannot set down the nature of the transfer function between the input and output of the box from any basic principles. Here, especially, when you get into the sociological field, you have to go in for a great deal of research having to do with the question of "what happens if."

Now one way to get a start is illustrated for the urban housing problem that Jay Forrester has been working on here at the Sloan School; the way he did it was to work with John Collins, former mayor of Boston and head of the New Institute for Urban Systems Studies, in a series of 12 to 6 afternoon sessions, over a period of six months, with experts in the field trying to get them to come up with the relation between this parameter and that. When you put this in, what do you expect? Does the output versus the input go up or does it go down?

The whole value of the model is to allow investigation by simulation studies. The results depend on how good the starting assumptions are. You can make sensitivity studies and change cœfficients and things, and hopefully keep from getting too far from reality. A very interesting conclusion from the study of the urban housing model is that, within limits or error and in terms of what people thought were the input-output functions, many of the results that are produced are, as Dr. Forrester puts it, "counter-intuitive". In the case of slum housing, for example, you don't improve the situation by building more houses. The effects of a number of other actions can be developed that way, and are, to various degrees, surprising. So you raise the question, is this correct? Well, it is only correct to the degree that you can say that the bases on which you have carried out the simulation are correct.

Dr. Steven Kahne: I would like to change the subject slightly and get away from simulation, although I don't want to be presented as being either for or against it.

A problem that I think we are going to have and one I think we are starting to face already is that most people trained at universities are trained to work by themselves. They are trained to do individual research projects and write up a thesis by themselves. Most of the problems that we have been talking about in the last two days are problems which are interdisciplinary and not already formulated as control problems in our sense. It turns out that system description may come from one discipline but the constraints may come from another. I think we have to be aware of the fact that it is undoubtedly going to take team efforts to solve these problems; and many people, I am sure, are not prepared to work in teams.

Dr. Stuart Fleriage: I just wanted to add to what Dr. Kahne and Mr. Schuck had said. I am a psychiatrist and I have devoted myself primarily to clinical endeavor during my professional life. What I find is that I have a fairly good understanding, at least a beginning understanding, of a certain social system in which I am operating and which needs some further articulation and clarification.

What I think I need, as a person out there who knows what the problems are, is just the kind of thing Dr. Kahne mentioned -- the opportunity to sit down with you people or with people like you over a period of time.

I find myself in agreement with Prof. Williams when he says if you understand the process or if you get an approximation of understanding the process, then you have the opportunity to sit down and talk with someone about how to control it. I think that is right.

I think the important point here is that you fellows are here and the people you want to work with are out there. They are in their context. They know their problems. They know their frustrations. But you people are here; how are you going to get the two together? You talk about social problems, or as Mr. Gustafson did, large-scale problems. Really there are some very small-scale problems which, if you could begin to comprehend them and get them in hand, you would have a chance to do something like Mr. Foster mentioned last night; namely, to add a few of them together, component by component.

We can break a problem down into components. Take social misbehavior; how you find it; what you do with it. This is so qualitative I won't carry it on, but it can be done. Somehow the opportunities have to be arranged. If technology isn't enough, how are you going to get these people together with the people who know what their problems are?

Dr. Harold Kushner: I have a funny feeling when the word "interdisciplinary" is mentioned because I am not sure exactly what it means. Prof. Williams made a remark to this effect already. He said they had a chemical engineer and an electrical engineer working together, presumably in the province of electrical engineering. He said the chemical engineer learned control; the electrical engineer didn't learn very much chemical engineering. As it turned out, the chemical engineer is the man who helped you out in the long run.

Well, what role did the interdisciplinary concept play in the process? I think control itself is interdisciplinary. Is a combination of mechanics and mathematics interdisciplinary or is it not? I think in the long run, in many problems, it is the ideas of a single man, of many single men: those individual things written down with eloquent persuasion which other people read. Even though this man may talk to many other people, he may get ideas in discussion with other people. He may participate in committee work. He may learn a great deal by being questioned and asking questions of other people. But I think if one is to do anything serious on any problem, he has to know a lot about different aspects of the problem, perhaps the mathematical and sociological aspects. There must be some man in there who has a command of a lot of things. Because, it seems to me, if one leaves things to the interdisciplinary group, there is no man who knows enough about all aspects of the problem to sum them up into something that somebody else can learn. It will always be a bunch of things here and there. Somehow there must be a man who knows a lot of things, a lot of different things, someone who knows how to cut short here and there.

I don't mind the word "interdisciplinary" provided one says or takes it with a certain sense of modesty, but I have the feeling that in many circles it is just an okay word. The interdisciplinary approach is often offered as a panacea – you just get people with different expertises together and somehow something important will come out of it.

Professor Zadeh: The word "interdisciplinary" was on the list of okay words until two or three years ago, but it is no longer.

Dr. Kahne: I would like to give two examples of interdisciplinary work: one is a psychiatrist and systems engineer; the other is the transportation engineer or the control engineer and the architect, who is building a station for a downtown transportation system.

Mr. Biernson: I think that the essence of the control problem is approximation. In other words, if you are trying to build a complicated control system, the problem is taking all of these things and reducing them to some equations that really are meaningful. This is the problem.

Now, I think one of the troubles with our research in the field of control over the last 10 years is that so much of it has emphasized what do we do with these control equations. How do we build an optimum system that satisfies these equations which are merely approximations? A lot of analysis has missed the fact that the real problem is getting the approximation and understanding the approximation. In other words, the real problem of control is really a question of approximation. If we recognize that we are always dealing with approximation with anything beyond a very simple system, we also realize that our analysis and simulation is not an end in itself. The mere fact that we have proved that these approximation equations give this result does not mean that the actual application will give that result. Therefore, along with the analysis, we must have experiments; and the thing that is missing in our research on control is that after we have done

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